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Acidic Deposition and the Corrosion and
Deterioration of Materials in the
Atmosphere: A Bibliography, 1880-1982

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ACIDIC DEPOSITION AND THE
CORROSION AND DETERIORATION OF MATERIALS IN
THE ATMOSPHERE: A BIBLIOGRAPHY. 1880-1982

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ABSTRACT

Materials exposed to the atmosphere are subjected to a wide variety of stressing agents such as wind, solar radiation, temperature, biological species, many forms of water, and chemical species including pollutant gases, particulate matter, and components of rainfall, dew, snow, sleet, fog and aerosols. This bibliography contains more than 1300 article citations and abstracts on the effects of acidic deposition, air pollutants, and biological and meteorological factors on the corrosion and deterioration of materials in the atmosphere. The listing includes citations for the years 1950 to 1982, with selected citations for the years 1880 to 1949. The citations are catalogued by year in six sections for metallic materials--ferrous alloys, aluminum, copper, nickel, zinc and galvanized steel, and other metals-- and six sections for nonmetallic materials--masonry, stone and ceramics, elastomers, fabrics, paints, plastics and other nonmetals. An author index and an index of chemical, biological, and meteorological variables are provided.

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INTRODUCTION

Materials exposed to the atmosphere are subjected to a wide variety of stressing agents, including: wind, solar radiation, temperature, biological species, water in its many forms, and chemical species including pollutant gases, particulate matter, and components of rainfall, dew, snow, sleet, fog, and aerosols. While each of these agents may contribute to the deterioration of materials, in most cases it is the combination of two or more of the agents that cause the more significant damage.

This bibliography contains an extensive listing of abstracts of publications and reports dealing with the effects of natural and polluted atmospheres on materials, including the effects of acidic deposition. Both peer-reviewed and grey literature have been included. No attempt has been made to define the term "acidic deposition;" instead, the literature was searched for all reasonable material and chemical, biological, and meteorological interactions. A detailed discussion of the strategy used in the search is given later.

Owing to the complicated processes occurring during deterioration of a material, a very large number of studies have been conducted in attempts either to ascertain the agent responsible for a certain type of damage to a specific material or to determine the best materials to use in certain types of characterized environments. In the former case, most work has been conducted in laboratory environments where the suspected pollutant or other agent could be introduced under controlled conditions. In the latter case, materials have been field tested in somewhat arbitrarily designated "typical" rural, urban, industrial, and marine environments. In only a few field studies has any attempt been made to monitor the air quality and meteorological variables during the exposure. Virtually no studies have been reported of attempts to determine the effects of "acidic rain" on materials.

For structures comprised of a number of materials and subject to local microclimates, an analysis of the causes of deterioration becomes even more difficult and even the definitions of "damage" may change. Certainly, the analysis is usually much more descriptive and subjective compared to that for single, well-characterized materials. Even with these sorts of difficulties, a large amount of useful information exists regarding the effects on materials

that result from contact with the environment. It is, however, important for the reader to understand that a large proportion of the literature contained in this bibliography resulted from studies having limited scope. Since it was not possible to predict the information desired by any particular reader, no critical assessment of this literature has been attempted. Through the various sections of the bibliography and the indexes, the reader should be able to determine the extant literature for a given combination of material with chemical and/or biological agent and meteorological variable.

One of the earliest surveys of materials damage due to pollutant gases in the atmosphere was the 1939 Bureau of Mines Information Circular on the "Effect of Sulfur Compounds in the Air on Various Materials" (I.C. 7064, L.R. Burdick and J.F. Barkley, 9 pp.). It reflected an already growing concern with the potential effect of air pollution on materials deterioration in the atmosphere. The materials covered included cement, stone, paint, leather, paper, cloth, copper, nickel, steel and zinc. Twenty-seven references were cited. Similar reviews have been written in the intervening 40 plus years as the study of atmospheric corrosion has greatly expanded.

The present bibliography contains more than 1300 citations of articles on the effects of acidic deposition, air pollutants, and biological and meteorological factors on the corrosion and deterioration of materials in the atmosphere. Each citation is accompanied by an abstract of the contents of the article. The citations are indexed in twelve materials sections covering metallic and nonmetallic materials. Two indexes are provided for cross-referencing citations: (1) an authors index, and (2) an index of chemical, biological and meteorological variables. Many sources were consulted to insure as complete a record as possible of the pertinent literature. This included computer-assisted and manual searches of data bases, utilization of existing bibliographies, and the review of appropriate proceedings, publications and documents. Furthermore, reference lists to the many articles, proceedings, publications, books, and public documents available to the authors were combed for literature that belonged in the bibliography.

The coverage of the literature on atmospheric corrosion in this bibliography is intended to include all pertinent articles from the years 1950 to 1982. For the years prior to 1950 the coverage is incomplete but includes at least the more important articles from these earlier years. This has

resulted in coverage extending, in some cases, back to 1880. The following sections describe the principal data bases used in compiling the bibliography, the indexing of citations, and the structure and arrangement of the materials sections, the author index, and the index of chemical, biological, and meteorological variables.

DATA BASES

Table 1 lists the data bases that were searched by computer. The strategies used to perform these searches are indicated in the last column and described in the footnotes to the table. The parentheses in these footnotes describe the sets of data considered and "AND" refers to the union of these sets of data. Thus, the computer searches produced the subset of data common to the two (or three) larger data sets. The dates covered by the computer searches are shown in table 1.

Table 2 lists the data bases that were manually searched. There was considerable overlap between the manual and computer searches of some data bases. However, the manual search was a productive source of articles that would otherwise have been missed. The Art and Archaeology Technical Abstracts files and the periodical and reprint files of the Conservation Analytical Laboratory were significant sources of literature, particularly foreign literature on the degradation and corrosion of materials in statuary, memorials, historical objects and structures, and artifacts.

Table 3 lists some earlier bibliographies that provided leads to articles on the corrosion and deterioration of materials. Table 4 lists publications, proceedings and documents containing extensive materials on the atmospheric corrosion and deterioration of materials. As noted earlier, the reference lists to these and many other publications were also combed for literature that belonged in the bibliography.

Table 1 - Computer searched data bases.

DATA BASE	SUPPLIER	DATES COVERED	SEARCH STRATEGY
A. DIALOG Information Retrieval Service			
ARGICOLA	National Agri- cultural Libr- ary	1970 - 1981	1
APTIC	Manpower and Technical Information Branch, U.S. Environmental Protection Agency	1966-October 1978	1
ARTBIBLIOGRAPHIES MODERN	ABC-Clio, Inc.	1974 - 1980	2
CA SEARCH	Chemical Abstracts Service	1972 - 1980	3
COMPENDEX	Engineering Information, Inc.	1970 - February 1981 1970-1980	4 3
COMPREHENSIVE DISSERTATION INDEX	Xerox Univ. Microfilms, Inc.	1900-March 1981	5
CONFERENCE PAPERS INDEX	Cambridge Sci- entific Abstr- acts	1973-January 1981	4,6
ENVIROLINE	Environmental Information Inc.	1971 - February 1981 1971-1980	4 3
ENVIRONMENTAL BIBLIOGRAPHY	Environmental Studies Inst.	1974-December 1980	7
HISTORICAL ABSTR- ACTS	ABC-Clio, Inc.	1973 - 1980	5

Table 1 - Computer searched data bases (continued).

DATA BASE	SUPPLIER	DATES COVERED	SEARCH STRATEGY
METADEx	American Society for Metals	1966 - 1980	3
NTIS	National Tech. Infor. Service	1964 - 1980	3
POLLUTION ABSTRACTS	Cambridge Scientific Abstracts	1970-January 1981 1970-1980	1,6 3
SSIE CURRENT SEARCH	Smithsonian Science Info. Exchange	October 1977 - August 1980	3
WORLD ALUMINUM ABSTRACTS	American Society for Metals	1968 - 1980	3
B. British Museum, London, England			
CONSERVATION DATA BASE	British Museum	1974 - 1981	4
C. RECON Search, Technical Infor. Ctr. U.S. Dept. of Energy			
ENERGY INFORMATION	U.S. Department of Energy	1974 - 1980	8

¹ (Stone, Masonry, Concrete, Brick, Limestone, Marble, Bronze) AND (Air Pollution, Atmospheric Pollution)

² (Air Pollution)

³ (Atmospheric Corrosion, Atmospheric Corrosion Tests) AND (Air Pollution)

⁴ (Metal, Stone, Masonry, Concrete, Brick, Limestone, Marble, Bronze) AND (Deterioration, Corrosion) AND (Air Pollution, Atmospheric Pollution)

⁵ (Metal, Stone, Masonry, Concrete, Brick, Limestone, Marble, Bronze) AND (Deterioration, Restoration, Preservation, Conservation)

⁶ (Atmospheric Corrosion)

⁷ (Air Pollution, Atmospheric Pollution) AND (Atmospheric Corrosion)

⁸ (Metals, Aluminum, Copper, Nickel, Alloys, Steels, Rubbers, Glass, Asphalts, Cements, Ceramics, Paints, Nonmetals) AND (Corrosion, Weathering, Decomposition, Corrosive Effects, Corrosion Protection) AND (Acid Rain, Air Pollution, Sulfur Oxides, Nitrogen Oxides, Ammonia, Ozone, Humidity)

Table 2 - Manually searched data bases.

DATA BASE	SUPPLIER	DATES COVERED
Chemical Abstracts	Chemical Abstracts Service	1950 - December 1980
Corrosion Abstracts	National Association of Corrosion Engineers	1962 - 1982
Engineering Index	Engineering Information, Inc.	1950 - 1979
Periodical and reprint files of Conservation Analytical Laboratory	National Museum of American History, Smithsonian Inst., Washington, D.C.	All
Art and Archaeology Technical Abstracts	Institute of Fine Arts, New York University (for International Institute for Conservation)	1955-1981

Table 3 - Selected bibliographies containing references
to atmospheric corrosion and deterioration of materials

TITLE, AUTHOR, ORGANIZATION	REPORT NUMBER	DATE
A Bibliography on the Corrosion and Protection of Steel in Concrete. E. Escalante and S. Ito, National Bureau of Standards	Special Publica- tion 550	August 1979
Acid Rain. Smithsonian Science Information Exchange	None	Sept. 1980
Air Pollution Effects on Materials: 1964-August 1978 (NTIS Data Base)	NTIS/PS-78/1073	Oct. 1978
Air Pollution Effects on Materials: 1964-October 1979 (NTIS Data Base)	NTIS/PB80-801863	Dec. 1979
Air Pollution Effects on Materials: 1971-April 1978 (API Data Base)	NTIS/PS-78/1074	Oct. 1978
Air Pollution Effects on Materials: 1961-Sept. 1979 (API Data Base)	NTIS/PB80-801871	Dec. 1979
Health and Environmental Effects of Acid Rain: 1966 - 1979. N.S. Dailey and S.G. Winslow, Toxicology Information Response Center, Oak Ridge National Laboratory	NLM/TIRC-80/1	March 1980
Hydrochloric Acid and Air Pollu- tion: An Annotated Bibliogra- phy. Air Pollution Technical Information Center, U.S. Environmental Protection Agency	AP-100	July 1971
Long-Range Transport of Air Pollutants and Acidic Precipi- tation. Atmospheric Environment Service, Environment Canada	None	July 1980
Materials of Art and Archaeology Bibliography. N.S. Baer, Inst. of Fine Arts, New York Univ.	None	1980

Table 3 - Selected bibliographies containing references
to atmospheric corrosion and deterioration of materials
(continued).

TITLE, AUTHOR, ORGANIZATION	REPORT NUMBER	DATE
Selected Bibliography of Atmos- pheric Corrosion. F. Mansfeld, Office of Naval Research	AD-A064856	Jan. 1979

Table 4 - Proceedings, publications and documents containing extensive materials on the atmospheric corrosion and deterioration of materials.

PROCEEDINGS, PUBLICATIONS AND DOCUMENTS	PUBLICATION DATE
A. ASTM Special Technical Publications	
175 - Atmospheric Corrosion of Non-Ferrous Metals	1955
435 - Metal Corrosion in the Atmosphere	1967
558 - Corrosion in Natural Environments	1974
576 - Galvanic and Pitting Corrosion	1976
646 - Atmospheric Factors Affecting the Corrosion of Engineering Metals	1978
691 - Durability of Building Materials and Components	1980
727 - Electrochemical Corrosion Testing	1981
767 - Atmospheric Corrosion of Metals	1982
B. Other Publications	
Atmospheric Corrosion, edited by W.H. Ailor, Wiley, New York, N.Y.	1982
Conservation of Historic Stone Buildings and Monuments, National Academy Press	1982
Handbook of Corrosion Testing and Evaluation, edited by W.H. Ailor, Wiley, New York, N.Y.	1971
Metals in America's Historic Buildings, M. Gayle, D.W. Look and J.G. Waite, Heritage Conservation and Recreation Service, U.S. Department of the Interior	1980
Protection Against Atmospheric Corrosion, K. Barton, Wiley, New York, N.Y.	1973
C. Proceedings	
1st International Congress on Metallic Corrosion (London, 10-15 April 1961), Butterworths, London	1962
2nd International Congress on Metallic Corrosion (New York, 11-15 March 1963), National Association of Corrosion Engineers	1966
3rd International Congress on Metallic Corrosion (Moscow, 1966) Swets-Zeitlinger, Amsterdam	1969

Table 4 - Proceedings, publications and documents containing extensive materials on the atmospheric corrosion and deterioration of materials (continued).

PROCEEDINGS, PUBLICATIONS AND DOCUMENTS	PUBLICATION DATES
C. Proceedings - continued	
4th International Congress on Metal- lic Corrosion (Amsterdam, 7-14 September 1969), National Associa- tion of Corrosion Engineers	1972
5th International Congress on Metal- Corrosion (Tokyo, 21-27 May 1972), National Association of Corrosion Engineers	1974
5th Scandinavian Corrosion Congress (Copenhagen, 7-10 October 1968), Danish Corrosion Centre, Copenha- gen	1969
2nd International Symposium on the Deterioration of Building Stones (Athens, September 27-October 1, 1976), National Technical Univer- sity, Athens	1976
4th Triennial Meeting (Venice, 1975), ICOM Committee for Conservation, ICOM, Paris	1975
International Symposium on the Dete- rioration and Protection of Stone Monuments, UNESCO and RILM, Paris	1978
D. Documents	
Air Quality Criteria for Particulate Matter and Sulfur Oxides, Final draft, U.S. Environmental Protec- tion Agency	1981
Air Quality Criteria for Oxides of Nitrogen, Final draft, U.S. Envir- onmental Protection Agency	1981
Air Quality Criteria for Ozone and Other Photochemical Oxidants, Final draft, U.S. Environmental Protection Agency	1981

Table 4 - Proceedings, publications and documents
containing extensive materials on the atmospheric
corrosion and deterioration of materials (continued)

PROCEEDINGS, PUBLICATIONS AND DOCUMENTS	PUBLICATION DATES
Impact Assessment Working Group 1, Phase II Report (Draft), U.S. - Canada Memorandum of Intent on Transboundary Air Pollution	April 1982
The Acidic Deposition Phenomenon and Its Effects, Critical Assessment Document (Draft), Volume II, U.S. Environmental Protection Agency	October 1982

MATERIALS SECTIONS

The bibliography is divided into twelve principal sections according to the material that is at risk. These sections are identified in Table 5 and include 6 sections on metallic and 6 sections on nonmetallic materials. Citations are organized in the Materials Sections by year of publication, with the most recent years first. Within each year the citations are arranged alphabetically by title. This arrangement was chosen, rather than the conventional arrangement by author, because it emphasizes the contents of the article and facilitates the identification of articles of interest.

Each citation includes the title of the article, followed by the authors, name of journal or publication, volume and/or issue number, date of publication, page numbers and parenthetically the language of publication if it is not English. Since an article may treat more than one material, citations may appear in more than one Materials Section. However, abstracts are not repeated and the abstract accompanies only the first appearance of a citation, as determined by the order of the Materials Sections given in Table 5. All subsequent citations of the same article are indexed to this earliest citation so that the abstract is readily accessible.

Coding of the citations is done using the symbols given in Table 5, followed by the year of publication, and the number of the citation in the alphabetical sequence for the year. Thus, if a citation is number 12 in the "Copper Alloy" section for the year 19XX, the code for that citation is CuXX-12. Each citation is uniquely identified by such a code number. In the few cases of citations from the 1800's, the full year is written out, e.g., Cu18XX-12. Citations that are repeated in later sections are followed parenthetically by the code number for the initial citation of the article. For example, if the article cited above in the "Copper Alloy" section were also cited in the "Fabric" section, the citation in the "Fabric" section would end with the coded notation (CuXX-12).

Citations drawn from Chemical Abstracts are marked with an asterisk (*) following the citation. They can be ordered from the Chemical Abstracts Service, P.O. Box 3012, Columbus, Ohio 43210. Citations drawn from Engineering Index (Engineering Information, Inc.) are marked with a double asterisk (**) following the citation. They can be order from the Engineering

Societies Library, 345 East 47th Street, New York, N.Y. 10017. Citations from the Chemical Abstracts Service and Engineering Information, Inc., are copyrighted (c) and all rights are reserved. Permission has been granted for this copyrighted material to be used in the present work with the following conditions: No part of these abstracts may be reproduce or transmitted in any form or by any means, electronic or mechanical including photocopying, recording, or by any information storage and retrieval system without permission in writing from their Publisher. A number of citations were also drawn from Art and Archaeology Technical Abstracts, Institute of Fine Arts, New York University, New York, N.Y.

Some abstracts used the following general terms to identify the material at risk: metal, structural metal, metal structures, metal specimens, alloys, various alloys. The specific materials studied were determined from an examination of the full article when it was accessible. Otherwise, these terms were translated for purposes of this bibliography to mean ferrous alloys and zinc and galvanized steel. Because of the use of polymers in elastomers, fabrics, and plastics, there was not always a clear choice for assigning a citation to one of these sections. This problem also arose with the fabrics and other nonmetal sections. Dyes would belong in "Other Nonmetals" but dyes are used on fabrics and fading is often used to characterize the atmospheric deterioration of fabrics. Three citations that belong in the year 1980 are found in the year 1982 because of last minute changes in the bibliography.

AUTHOR INDEX

Approximately 1500 authors are listed in this index. The authors are listed alphabetically. Their publications are grouped following the format of the 12 materials sections in the bibliography. For each of these sections the citations are arranged by year with the most recent year first. Citations to publications are indexed using the code described earlier in the discussion of the Materials Sections. For citations repeated in several of the materials sections, only the earliest citation of the publication, e.g., that which is accompanied by the abstract, is catalogued in the Author Index. As an example, suppose J. R. Smith is cited in the Ferrous Alloy section for

Table 5 - Materials sections.

MATERIAL	SYMBOL	YEAR OF EARLIEST CITATION
Ferrous alloys	Fe	1919
Aluminum alloys	Al	1929
Copper alloys	Cu	1927
Nickel alloys	Ni	1929
Zinc and Galvanized Steel	Zn	1929
Other Metals	OM	1927
Masonry, Stone and Ceramics	MSC	1880
Elastomers	E	1931
Fabrics	F	1937
Paints	Pa	1939
Plastics	P	1950
Other Nonmetals	ONM	1937

publication 12 in the year 1957 and this citation is repeated in Zinc and Galvanized Steel, in Masonry, Stone and Cement, and in Paint. Also, J. R. Smith is cited in the Copper Alloy section for publication 3 in the year 1959. The Author Index would read:

Smith, J.R.
Fe: 57-12
Cu: 59-3

The listings by material should not be interpreted to mean that these were the only materials the author studied. Rather, they are the earliest appearance in the bibliography of those specific citations.

Some names, particularly several Russian names, appeared in the literature with slightly different spellings. When these various spellings clearly referred to the same author, one spelling was chosen and all of the authors citations were catalogued under that name.

CHEMICAL, BIOLOGICAL AND METEOROLOGICAL VARIABLE INDEX

All citations that discuss specific chemical, biological, and meteorological variables are identified in this index. However, water, water vapor, dew, rain, snow, ice, sleet, fog, moisture, and humidity were excluded because water is a common component in all corroding systems. All inorganic sulfur compounds except hydrogen sulfide were also excluded because the effects of sulfur oxides on the deterioration and corrosion of materials were considered in a majority of the citations.

This index has three principal sections: chemical variables, biological variables, and meteorological variables. Within these sections there are a number of subsections. Pertinent citations are catalogued under each subsection following the format of the 12 Materials Sections in the bibliography. The citations are indexed in exactly the way citations were indexed in the Author Index. In this scheme the listings by material should not be interpreted to mean that these were the only materials for which a particular chemical, biological, or meteorological variable was studied. Rather, they are the earliest appearance in the bibliography of those specific citations. However, the sum of the citations listed under any given variable constitutes all of the citations that refer to that specific variable.

Citations referring to a marine environment were catalogued under "Chloride". Citations that referred specifically to soiling were cataloged under "Soiling", otherwise, reference to particulates or particulate matter were catalogued under "Particulates-Other". Certain general phraseology was not interpreted with respect to the Chemical, Biological and Meteorological Variable Index without more specific information since the possible interpretations were numerous. Examples of these are: "rural", "industrial", "urban", "weathering", "weathering tests," "atmospheric pollutants", "atmospheric exposure," "polluted sites," "four sites", "atmospheric pollution," "natural atmospheres", "atmospheres at 7 locations", and "atmospheric corrosion". When phrases such as these were the only descriptors of the environment referred to in the citation, the citation was not catalogued in this index.

FERROUS ALLOYS

1982

1. A Probe for Monitoring Corrosion In Marine Environments. V. S. Agarwala. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 183-192.

A probe based on the principles of an electrochemical galvanic cell has been developed for continuous monitoring of corrosivity in the marine environment. An eight month evaluation of the probe has been made on an aircraft carrier during its deployment in the Mediterranean. The current transients monitored during this period have been analyzed and related to the similar measurements in laboratory controlled experiments. The results indicate a direct relationship between the probe current and the corrosivity of the environmental variables.

2. Accelerated Atmospheric-Corrosion Testing. M. Khobaid, F. C. Chang, E. E. Keppler, and C. T. Lynch. Atmospheric Corrosion of Metals, edited by S. W. Dean, Jr., and E. C. Rhea, American Society for Testing and Materials, ASTM STP 767, 1982, pp. 374-394.

No accurate methods are known for accelerated testing of corrosion which yield reliable results for predicting the service life of aircraft components and materials which degrade or fail due to environmental attack. In an effort to provide the basis for development of realistic accelerated corrosion tests, research is being conducted in controlled atmospheres on the localized environmental enhancement of crack-growth rates of aerospace alloys. Corrosion-fatigue and rising-load experiments have been conducted using accelerating pollutants such as sulfur dioxide and ambient air to 100 percent relative humidity air in a specially designed atmospheric chamber. Initial results indicate that realistic environmental enhancement of crack-growth rates can be employed to develop accelerated tests which can be related to actual in-service degradation. For materials with high stress-corrosion susceptibility, the threshold for crack growth (K_{Isc}) was estimated to be 45 to 46 MPa m for 4340 steel at a 1440 MPa yield strength level, as compared to 49 to 52 MPa m as determined by means of rising-load test and 44 to 46 MPa m by fracture analysis in 1000 ppm SO_2 at 80 percent relative humidity. Thus, a rapid and reproducible method for K_{Isc} determination appears feasible.

3. Acid Rain: Impacts on the Natural and Human Environment. H. C. Martin. Materials Performance, v. 21, No. 1, January 1982, pp. 36-39.

Acid rain is one of the most serious environmental problems of the decade. This paper reviews the current scientific assessment of the impact of acid rain on the natural environment. The costs incurred through damage to buildings and structures in North America are discussed with reference to relevant studies in Europe.

4. Airborne Contaminants and the Pitting of Stainless Steels in the Atmosphere. K. E. Johnson. Corrosion Science, v. 22, No. 3, 1982, pp. 175-191.

The present work was undertaken with the aim of determining the factors that lead to pitting of stainless steels in the atmosphere. Specimens of Types 430, 304 and 316 stainless steels were inoculated with the solid contaminants alumina, carbon, sodium chloride, ammonium sulphate and ferrous sulphate and exposed to humid atmospheres containing high (100-3000 ppm) and low (0-0.15 ppm) levels of sulphur dioxide. A synergistic effect was found with sulphur dioxide and sodium chloride; in the absence of sulphur dioxide little pitting was found with any of the contaminants investigated, including sodium chloride.

5. Atmospheric Corrosion and the Automobile. J. D. Palmer. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 705-710.

The atmospheric testing of materials and components for automotive service has varied considerably since automotive corrosion was recognized as a major problem in the 1950's. It became evident that the extrapolation of laboratory test results to service was very imprecise. A great variety of coupon shapes has been used for on-vehicle exposures. Electrical resistance probes were established as useful in providing short term environmental monitoring but require correlation with component or coupon weight loss to be accurate. Increasing reliance has been placed on full-vehicle exposure under natural or accelerated field conditions but there is considerable ignorance of most variables affecting automotive corrosion rates. Recommendations for the conduct of atmospheric testing for automotive service are presented and several areas worthy of investigation are outlined.

6. Atmospheric Corrosion of Bimetallic Structures. V. Kucera and E. Mattsson. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 561-574.

The following parameters of importance are discussed: the electrode potential difference, the anodic and cathodic polarization and the existence of passivating coatings, the distance between anodes and cathodes, the thickness of the moisture film on the surface, and the influence of atmospheric pollution. Some field test methods are described including the circular disk method, the wire-on-bolt method, combination of plates of dissimilar metals, and electrochemical test methods. Important published investigations are surveyed, and some charts are presented, useful in materials section.

7. Atmospheric Corrosion of Fastener Joints. E. Taylor. Extended Abstracts, International Symposium on Atmospheric Corrosion (October 5-10, 1980, Hollywood, Florida), Electrochemical Society, v. 80-2, 1980, pp. 609-610.

The galvanic compatibility of the various metals used in joints, composed of threaded fasteners and structural components was studied after exposure for up to 3 years at unrelated global locations in Anasco, Puerto Rico; Coventry, England; Jenkintown, Penn.; Kure Beach, N.C.; Nunawading, Australia; Santa Ana, CA; and Tokyo, Japan. Some of the results from this study can be utilized to recommend alloys and coatings which are galvanically compatible in specific geographical areas or multi-locations.

8. Atmospheric Corrosion of Malleable and Cast Irons and Steels. C. McCaul and S. Goldspiel. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 430-452.

The paper reviews literature on atmospheric corrosion of malleable and cast irons and steel, with emphasis on factors which influence it and methods for testing. It attempts to organize material and data so that it may be useful to designers and engineers. It indicates limitations relating to environmental factors and variables recognized at this time, provides comparisons between these cast material types and their wrought counterparts, and points to additional work needed in the field.

9. Atmospheric Corrosion of Metals in the Tropics. C. R. Southwell and J. D. Bultman. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 943-968.

The tropics, where consistent weather patterns and low air pollution usually prevail, provide reliable data for establishing corrosion rates of metals in natural environments. In a study conducted in Panama 52 metals were evaluated for 16 years in both single-metal and bi-metallic exposures. Results are presented in detail and the data used to determine final constant corrosion rates. Other tropical corrosion investigations are reviewed; these furnish additional information for some alloys as well as relative corrosivity of different tropical locations.

10. Atmospheric Corrosion of Metals Under Moving Conditions. J. D. Talati and B. M. Patel. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 695-704.

Atmospheric corrosion of mild steel, zinc, and aluminum has been studied under moving conditions by exposing specimens on a railway coach running between Ahmedabad and Bombay. The monthly rates of corrosion ranged from 5-12, 76-329, and 582-2196 mg/dm² for Al, Zn, and mild steel, respectively; the yearly rates being 53-66 (Al), 1026-1168 (Zn), and 8333-10408 mg/dm² (m.s.). Monthly rates are higher during June-August (high humidity and rainfall) and lower during December-March (lower temperatures, no rainfall). Painted specimens did not show any corrosion during the period of study.

11. Atmospheric Corrosion of Stainless Steel. M. J. Johnson and P. J. Pavlik. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 461-474.

The various types of stainless steel and their corrosion resistance to various atmospheric environments are discussed. The types of stainless steel used in various applications and their performance are also presented. Published data by various investigators are cited and new data on some of the more recently developed alloys are listed. An extensive bibliography is included in the paper.

12. Atmospheric Corrosion of Weathering Steels. D. Knotkova-Cermakova, J. Vlckova, and J. Honzak. Atmospheric Corrosion of Metals, edited by S. W. Dean, Jr., and E. C. Rhea, American Society for Testing and Materials, ASTM STP 767, 1982, pp. 7-44.

A general research program to study the corrosion behavior of weathering steels is being completed by the State Research Institute for Materials Protection. Three stages of research are discussed:

1. a description of the corrosion characteristics of these materials,
2. the corrosion behavior of weathering steels in structural service, and
3. the evaluation of the applicability of weathering steels for typical real structures.

The results of this program were used to formulate the corrosion section of the specification: Technical Direction for Application of Weathering Steels.

A comparison of the cost of construction using conventional paint coatings on steel versus the use of weathering steel is provided, including the protection and operation of construction.

13. Atmospheric Corrosion Studies on Stainless Steels and Low Alloy Steel in a Marine Atmosphere. A. S. Khanna and J. B. Gnanamoorthy. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 489-500.

Specimens of austenitic stainless steels and a low alloy ferritic steel with different fabrication and heat-treatment histories were mounted on three panels, located about 100 km from sea and exposed to the marine atmosphere of Kalpakkam. The results of observations on these specimens for one to three years are reported in this paper. Sensitized specimens had been extensively pitted and stressed or welded specimens had not developed any crack.

14. Atmospheric Corrosion Testing by Electrolytic Cells in Norway and Sweden. S. E. Haagenrud, V. Kucera, and J. Gullman. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 669-694.

The electrochemical technique is based on measurement and integration of the current in electrolytic cells with an external imposed d-c voltage.

The use in several applications is described, i.e., the influence of environmental parameters on the cell current and time-of-wetness, comparative studies of corrosion properties of different alloys, and analysis of the corrosion environment in an industrial plant. The possibilities and limitations of the technique are discussed.

15. Atmospheric Corrosion Testing in Australasia. J. F. Moresby, F. M. Reeves, and D. J. Spedding. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 745-754.

The history and details of testing metals and coatings in tropical, sub-tropical temperate, and sub-antarctic climates in Australia and New Zealand are described. Test sites vary from 3m to 600 km from the sea, and some in N.S.W. approach Kure Beach, N.C. for severity. A unique corrosivity survey of 900 km² of Melbourne is in progress using BISRA type steel coupons. This follows an earlier survey in 1961 and an Australia wide 1968-1979 survey of cladding materials. Geothermal environments in N.Z. with wet steam and H₂S are discussed. Current government agencies' and private companies' tests of coatings range from semi-desert to rain forest locations.

16. Atmospheric Corrosion Testing in Brazil. A. C. Dutra and R. Vianna. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 755-774.

Atmospheric corrosion represents more than half of the total cost of corrosion. Testing in actual field conditions is a must as it is rather difficult to reproduce those conditions in the laboratory. The behavior of an electrode under thin layer electrolyte differs largely from that when immersed in a large volume. Atmospheric corrosion testing in Brazil is recent but locations of testing sites represent the most important climates. ABRACO (Brazilian Corrosion Association) has had an important role in establishing technical norms and standardized procedures.

17. Atmospheric Corrosion Testing in Finland. T. Hakkarainen and S. Ylasaari. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 787-796.

Typical features of the Finnish climate and levels of concentrations of atmospheric pollutants are described briefly. Corrosion tests include outdoor exposures of mild steel, low alloy Cr-steel, hot dip galvanized steel, zinc, and galvanic couples of dissimilar metals, as well as laboratory experiments on the effect of concrete powder and soot on some metals. Factors affecting the atmospheric corrosion rates are discussed and some future trends in atmospheric corrosion testing in Finland are outlined.

18. Atmospheric Corrosion Testing in the Federal Republic of Germany. G. Oelsner. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 797-806.

Predictions about the expected corrosion behavior of metals and alloys under atmospheric conditions are only possible by long-term exposure. A quantitative measurement of special properties is absolutely necessary. A way to describe the aggressiveness of the atmosphere is to measure the corrosion rate of different metals. The welds of galvanized steel constructions were protected best by zinc sprayed coatings with subsequent paint coatings. For the investigation of the corrosion behavior of aluminum materials, 12 different aluminum alloys were tested. Anodized samples were also tested.

19. Atmospheric Corrosion Testing in Japan. T. Fukushima, N. Sato, Y. Hisamatsu, and I. Matsushima, and Y. Aoyama. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 841-872.

Ten year exposure tests of steels estimated the corrosion loss ranging from 0.05 to 0.90 mm depending on the location. Regression equations relating the corrosion loss of steels to the environmental factors were obtained. Aluminum alloys exposed for 20 years suffered from pitting corrosion 0.004-0.277 mm in depth. Mechanisms of atmospheric corrosion are discussed.

20. Atmospheric Corrosion Testing in Norway. L. Atteraa and S. E. Haagenrud. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 873-892.

The Norwegian Institute for Air Research (NILU) and VERITAS have conducted long term tests in marine, industrial, and other atmospheres on aluminum, zinc, carbon steel, and weathering steel. Nineteen sites are in Norway and twelve in Sweden. Attempts to correlate laboratory results with those from field tests using environmental data have been carried out. Metallized and painted steels have also been studied.

21. Atmospheric Corrosion Testing in Southern Africa. B. G. Callaghan. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 893-912.

Extensive atmospheric corrosion programs have been carried out in Southern Africa to evaluate the performance of metals, alloys, metal coatings, duplex coatings (metal and organic), and paint coatings. Corrosion rate data is provided on various steels, low alloy steels, stainless steels, copper alloys, and aluminum alloys at sites ranging from severe marine, industrial marine, industrial highveld (low relative humidity, high solar radiation) to rural. Coatings exposed include galvanized steel, thermally sprayed coatings of zinc and aluminum, and electroplated coatings of zinc and cadmium.

22. Atmospheric Corrosion Testing in Spain. S. Feliu and M. Morcillo. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 913-922.

Atmospheric corrosion aggressivity in Spain is being studied with the help of various networks of test sites, covering urban and rural areas as well as a number of industrial and/or marine locations. The corrosion levels for mild steel, zinc, copper and aluminum in pure atmospheres have been ascertained and relationships between corrosion and pollution suggested. Initial results of long-term tests for determining the kinetic expression of atmospheric corrosion are discussed. Corrosion inside louvered boxes is compared with that in the open air.

23. Atmospheric Corrosion Tests in the USSR. Y. N. Mikhailovskii and P. V. Strekalov. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 923-942.

The published information describes the network of base atmospheric exposure stations of the Institute of Physical Chemistry of the USSR Academy of Sciences which are located in the vicinity of Murmansk, Moscow, Zvenigorod, Batumi, and Vladivostok, i.e., in the most characteristic climatic zones of the USSR (the Middle-European and the Asian parts of the USSR, the Arctic, the subtropics). The main climatic characteristics of the atmospheres, average concentrations of air pollutants, and the frequencies of parameters determining the corrosive aggressiveness of atmosphere are cited. The structure of stations, the meteorological and testing equipment applied are described. Corrosive behavior of the basic structural metals, steel, copper, zinc, aluminum, in atmospheric conditions is analyzed.

24. Atmospheric Marine Corrosion of Structural Steels. B. R. Meybaum and E. S. Ayllon. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 423-429.

Test samples of three weathering steels, CorTen A, B and B-QT, and SAE 1010 steel were exposed for different periods and surface finishing at the Marine Test Station of CAMET, Buenos Aires, Argentina. Polarization of weathered samples showed a passivating effect due to the developing "patina." SEM analysis evidenced the localized nature of the beginning and propagation of the corrosion process. The attack nucleates selectively causing ferrite dissolution, springing up from the steel surface the cementite phase.

25. Atmospheric and Weather Factors in Corrosion Testing. H. Guttman. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 51-68.

This paper reviews techniques for measuring climatic/atmospheric factors that are known to have an effect on the corrosion of metals. It discusses corrosion rate studies carried out in conjunction with measurements of atmospheric factors. The need to direct future research effort to take into account conditions of actual service is stressed. Such conditions include orientation, degree of shelter, effects of corrosion product and/or foreign materials, and others. The importance of time-of-wetness of a corroding substrate is discussed in detail.

26. Automotive Corrosion in India. G. V. Ramanaiah, S. D. Chirputkar, and B. L. Dhar. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 711-716.

The paper is a study on the influence of different atmospheric conditions on corrosion behavior of automobiles in India. Area corrosion, crevice corrosion, pitting and localized corrosion, fili-form corrosion, and stress corrosion are the types of corrosion dealt with in the paper. Further, the influence of different anticorrosive treatments on corrosion resistance is described. Lastly, the contribution of corrosion in vehicle accidents is touched.

27. Calibration of Atmospheric Corrosion Test Sites. E. A. Baker and T. S. Lee. Atmospheric Corrosion of Metals, edited by S. W. Dean, Jr., and E. C. Rhea, American Society for Testing and Materials, ASTM STP 767, 1982, pp. 250-266.

Inherent in the ability to accurately assess the performance of a material exposed in the atmosphere is an understanding of the relative corrosivity of that environment. The most reliable of present test methods for ranking materials' corrosion behavior have necessarily utilized long-term exposures to the natural environment in question. Given the variable nature of many atmospheric factors, it becomes important to determine the relative stability in the corrosivity of an atmospheric exposure site. Only in this way can the desired credence be given to atmospheric corrosion data generated for a variety of materials over an extended duration.

A review is provided of the major factors which must be considered in establishing a program to monitor and calibrate an atmospheric test site. These factors include both environmental assessments and corrosion evaluations. Consideration is given to the specific environmental parameters which could be monitored as well as experimental procedures which affect the atmospheric corrosion behavior of materials.

28. Colloid and Surface Phenomena in the Corrosion of Metals. E. Matijevic. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 123-138.

Colloidal hydrous oxides of various metals consisting of particles uniform in size and shape have been prepared under conditions which simulate different corrosion situations. These systems are then used to elucidate chemical processes leading to nucleation and growth of such model corrosion products. Furthermore, magnetic, optical, electric, and absorptive properties of such monodispersed metal (hydrous) oxides are investigated, as well as their interactions with various solutes of interest in corrosion inhibition or chemical cleaning of the crud. Finally, adhesion phenomena of these particles on various substrates and their detachment from surfaces as a function of different parameters are illustrated and theoretically explained.

29. Control of Atmospheric Corrosion Pollutants in Great Britain. F. F. Ross and T. P. Shaw. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 19-30.

Control of emission of corrosive and other gases began 115 years ago. Gas washing for sulfur dioxide was started in 1928 and largely abandoned around 1960. Rules for chimney design were introduced in 1955 and prohibition of smoke was extended from 1956 onwards. These two measures have reduced the average urban concentration of sulfur dioxide by 70%. The corrosiveness of the atmosphere has been, and is maintained on a yearly update basis.

30. Controlling Features in Atmospheric Corrosion of Steel. B. R. Meybaum and E. S. Ayllon. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 501-508.

The atmospheric corrosion study was approached analyzing separately the anodic and cathodic reactions occurring on the steel surface. With this purpose, positive and negative overpotentials were applied to the test samples in rainwater of urban-industrial and marine environments. Anodic polarization originated, by selective ferrite dissolution, geometrical pits with polished walls and bottoms, corresponding to definite crystallographic plans. Negative overpotentials produced steel blistering. Both of these characteristic attacks were also found in the respective outdoor tests.

31. Corrosion Aggressivity of Atmospheres (Derivative and Classification). D. Knotkova-Cermakova and K. Barton. Atmospheric Corrosion of Metals, edited by S. W. Dean, Jr., and E. C. Rhea. American Society for Testing and Materials, ASTM STP 767, 1982, pp. 225-249.

Corrosivity classification of the atmosphere is important for selecting optimal protective systems. This classification should be based on an understanding of the corrosion process together with reasonable engineering principles. By a critical analysis of the factors providing limits to the classification problem, several heretofore unresolved questions have been answered. These questions involve design factors, effects of different types of sheltering, fabrication effects, and the transformation of measured values to information which can be utilized technically. The Czechoslovakian system of standards covering this field is described and complemented by examples of specialized specifications for different industries. Questions for further research are proposed in order to further the classification efforts.

32. Corrosion Fatigue of Metals in the Atmosphere. I. H. Craig and R. N. Perkins. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 969-982.

A critical review of the literature in relation to the fatigue of metals and alloys in natural humid atmospheres is presented. Emphasis is placed on the proposed mechanisms of fatigue in humid environments and an

attempt is made to rationalize the various mechanisms in terms of the kinetics and thermodynamics of the interactions involved in the fatigue process.

33. Economic Assessment of Pollution Related Corrosion Damage. F. H. Haynie. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 3-18.

The importance of corrosion as a product life limiting factor will increase with the necessity to conserve limited resources. Thus, an economic model to assess pollution related corrosion costs becomes a useful decision tool. Physical damage, geographic distribution, maintenance, replacement, substitution, and value lost due to decreased utility or appearances are incorporated into this model. These interrelated factors are subject to individual decisions, which can be assumed in calculating best, worst, and most likely cases for different pollution levels.

34. Eight-Year Atmospheric Corrosion Performance of Weathering Steel in Industrial, Rural, and Marine Environments. H. E. Townsend and J. C. Zoccola. Atmospheric Corrosion of Metals, edited by S. W. Dean, Jr., and E. C. Rhea, American Society for Testing and Materials, ASTM STP 767, 1982, pp. 45-59.

Weathering steel (ASTM A588, Grade B) and steels with 0.021 and 0.21 percent copper were tested for corrosion resistance in marine, rural, and two industrial environments. The results of these tests are represented well by kinetic equations of the form $C = AT^B$, where C is the corrosion loss, T is time, and A and B are constants. On the basis of the time required to achieve a 250 μm (0.01 in.) thickness loss that is calculated using these equations, the weathering steel is 6 to 19 times more durable than 0.021 percent copper steel and 2 to 10 times more durable than the 0.21 percent copper steel.

35. Electrochemical Methods for Atmospheric Corrosion Studies. F. Mansfeld. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 139-160.

Past and present efforts to use electrochemical techniques for the evaluation of atmospheric corrosion phenomena are reviewed. Techniques for the determination of the time-of-wetness t_w and the recent controversy concerning the definition of t_w are discussed. Various approaches for measurements of atmospheric corrosion rates and the question of the efficiency of electrochemical sensors ("cell factor") are evaluated. Recent results obtained in the author's laboratory concerning the reproducibility of electrochemical measurements in a statistically designed experiment under atmospheric corrosion conditions (15 sensors of one type; RH = 65, 80, 95%; 0.1 or 1.0 ppm SO_2) are presented.

36. Electrotopography - A New Tool for Corrosion Research. M. Ensanian. Extended Abstracts, International Symposium on Atmospheric Corrosion (October 5-10, 1980, Hollywood, Florida), Electrochemical Society, v. 80-2, 1980, pp. 480-482.

This communication attempts to briefly summarize a new methodology and some of the highlights of a large body of experimental knowledge, collectively referred to as electrotopography. It is based upon a new and unique form of rotational contact, nonequilibrium, electrochemical potential, and represents a powerful new tool for the characterization of complex solids (alloys, semiconductors, and metalloids) and their surfaces, under both static and dynamic conditions. Topological invariance considerations are discussed.

37. Environment, Microenvironment, and the Durability of Building Materials. P. J. Sereda and H. E. Ashton. J. Durability of Building Materials, v. 1, No. 1, 1982, pp. 49-66.

This paper reviews the state-of-the-art regarding the monitoring and importance of environmental factors of temperature, moisture (precipitation and relative humidity), solar radiation, and pollution. These factors are related to the microenvironment to which building materials in a structure are exposed. Evidence is reviewed regarding the importance of microenvironment on the specific processes of corrosion and deterioration and thus on the performance of building materials. Methods of monitoring the microenvironment are reviewed, especially in connection with the measurement of the time-of-wetness and UV irradiation. Areas where information is lacking, as in the case of effects of pollutants, including acid rain, are identified.

38. Evaluation of Corrosivity of Various Atmospheres. T. Zak and G. Chojnacka-Kalinowska. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 217-226.

The atmospheric corrosion of low-carbon steel in various climatic conditions (at 14 weather-forecast stations located in different regions of Poland) was examined. Corrosion losses were determined at monthly intervals for two years. The results obtained were correlated with meteorological parameters and SO_2 concentrations. Suitability of one- and multi-parameter equations was statistically determined. The best results were obtained when correlating the corrosion rate (K) and the time when the specimen is wet. The wet time was calculated from the difference of air and dew point temperatures using the equation $K = at_B + b$ where a and b are the regression coefficients. This equation was found as most suitable for predicting the corrosion losses on the territory of Poland.

39. Evaluation of the Effects of Microclimate Differences on Corrosion. F. H. Haynie. Atmospheric Corrosion of Metals, edited by S. W. Dean, Jr., and E. C. Rhea, American Society for Testing and Materials, ASTM STP 767, 1982, pp. 286-308.

Analytical and statistical analyses of data obtained from a contracted exposure study performed by Rockwell International in St. Louis, Mo., reveal that many microclimate differences can account for observed differences in corrosion behavior within a geographic region. Data from Mansfield's Atmospheric Corrosion Monitors (ACM's) were evaluated with data from the Regional Air Monitoring System (RAMS). Relative humidity, temperature, wind speed, and levels of total sulfur gases, such as sulfur dioxide, and oxides of nitrogen were found to be statistically significant variables. Problems of covariance were avoided by partitioning the large data set into subsets.

Relative humidity was found to be the most important but least accurate variable. Because it is seldom measured at exposure sites, an equation was developed to relate site-to-site relative humidity differences to temperature differences. With average relative humidity and another empirical equation, time-of-wetness can be estimated. The results are in good agreement with time-of-wetness from the ACM's.

40. Indoor Corrosion Testing. W. O. Freitag. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 265-274.

An Accelerated Business Environment (ABE) test was developed to determine the vulnerability of magnetic alloys to atmospheric attack in computer environments. The atmosphere consists of 300 ppb SO₂ and 300 ppb NO₂ in air at 20°C and 75% RH. FeNi and NiCo films are visibly attacked in 6 hr and are pitted in 24-48 hr. The corrosion products formed at the pits contain sulfur and chlorine, as measured by EDX. The general validity of the ABE test was established by comparing its effects with those of 5000 hr exposure to various indoor ambients. The morphology of the corrosion is the same in ABE as in the ambients.

41. Influence of Accelerated Weathering on the Corrosion of Low-Alloy Steels. H. Schwitzer and H. Bohni. J. Electrochem. Soc., v. 127, No. 1, 1982, pp. 15-20.

In low-alloy steels under accelerated atmospheric corrosion conditions, the type of weathering, particularly the ratio of the time-of-wetness to the drying time, has a greater influence on the corrosion behavior than does the composition of the alloys. Electrochemical measurements show that the rust protection is not only due to the formation of compact macroscopic protective layers, but also to passivation effects. Passivation occurs for a prolonged period only at favorable accelerated weathering conditions. A model for the interpretation of the corrosion behavior of low-alloy steels is proposed.

42. Measurement of the Time-of-Wetness by Moisture Sensors and Their Calibration. P. J. Sereda, S. G. Croll, and H. F. Slade. Atmospheric Corrosion of Metals, edited by S. W. Dean, Jr., and E. C. Rhea, American Society for Testing and Materials, ASTM STP 767, 1982, pp. 267-285.

A 1-year program involving several laboratories located in different climatic zones has afforded an opportunity to evaluate the response of

miniature moisture sensors (developed at the National Research Council of Canada) to surface moisture on panels exposed to the atmosphere. It has shown that when these moisture sensors are placed on the surface of metal or plastic panels, they respond to moisture conditions at the surface or, more precisely, at the sensor surface, and that such moisture conditions result from interaction of the total environment with the material as well as with the ambient relative humidity conditions.

43. Prediction at Long Terms of the Atmospheric Corrosion of Structural Steels from Short-Term Experimental Data. A. A. Bragard and H. E. Bonnarens. Atmospheric Corrosion of Metals, edited by S. W. Dean, Jr., and E. C. Rhea, American Society for Testing and Materials, ASTM STP 767, 1982, pp. 339-358.

Two experimental laws expressing the relationship between the weight losses and the time of exposure allow a fair assessment of the corrosion evolution of steels in numerous sites. The simultaneous existence of these two laws implies intercorrelation between the coefficients of the empirical equations. The effects of the climatic and pollution factors on these coefficients are discussed. It is suggested to represent the corrosiveness of a test site toward a steel grade by the one-year weight loss, and the further evolution of corrosion as a function of this weight loss and the relative humidity of the site.

44. Progress in Atmospheric Corrosion Testing. D. Knotkova-Cermakova, K. Barton, and M. Cerny. Extended Abstracts, International Symposium on Atmospheric Corrosion (October 5-10, 1980, Hollywood, Florida), Electrochemical Society, v. 80-2, 1980, pp. 526-528.

Atmospheric corrosion testing on sites is an important component of a system comprising basic research of the mechanisms and kinetics of corrosion, deterioration processes of protection coatings, classification of the aggressivity, etc. Testing sites should be erected as a complex network representing typical characteristics and have to be well organized and technically equipped (examples--the national Czechoslovak system, the international network of sites of the COMECON). The testing activities include programs with models simulating products and structures. The examples of complex testing programs and their evaluation and utilization are presented. Actual problems in atmospheric corrosion testing (influence of design factors, corrosion under shelters, general technical interpretation of information) are formulated.

45. Rapid Methods for Determining Atmospheric Corrosivity and Corrosion Resistance. D. P. Doyle and T. E. Wright. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 227-244.

The paper deals with the CLIMAT (Classification of Industrial and Marine Atmospheres) test, which is used, as the name implies, to classify atmospheric corrosivity for a given location. Experience is mainly with aluminum and its alloys but some work with other metals has also been done. The paper also describes the SIMAT (Simulation of

Industrial and Marine Atmospheres) test, which has been developed in order to obtain accelerated test data on various aluminum alloys, relating to atmospheric applications.

46. Reproducibility of Electrochemical Measurements of Atmospheric Corrosion Phenomena. F. Mansfeld, S. Tsai, S. Jeanjaquet, E. Meyer, K. Fertig, and C. Ogden. Atmospheric Corrosion of Metals, edited by S. W. Dean, Jr., and E. C. Rhea, American Society for Testing and Materials, ASTM STP 767, 1982, pp. 309-338.

A brief discussion is given of recent efforts to use electrochemical techniques for monitoring of atmospheric corrosion phenomena. Problems existing with the interpretation of time-of-wetness measurements are identified, and the finding that electrochemical sensors in their present design and application determine only fractions of the true corrosion rate is discussed. In order to resolve some of these difficulties, a statistically designed experiment is being carried out to evaluate the reproducibility of electrochemical measurements of atmospheric corrosion phenomena and to determine the effects of sensor design on time-of-wetness and cell efficiency. Results are presented for the first phase of this project, in which 15 atmospheric corrosion monitors (ACM), each of the copper/steel and steel/steel type, have been fabricated with steel and copper from three different heats. These ACM's have been tested in triplicate runs by exposure to aqueous .001M sodium chloride at a relative humidity of 45 percent until the surface had dried out, followed by additional exposure to either a moist air environment at three levels of relative humidity (65, 80 and 95 percent) or a sulfur dioxide (SO₂) test at three levels of SO₂, approx. ≈ 0 , 0.2, and 1.1 ppm. During each test, steel plates from each heat were exposed to determine weight loss data. At present, only the drying-out data have been analyzed by statistical methods. It has been found both from electrochemical and weight loss data that the heat of the steel plays an important role, with one heat corroding at a higher rate than the other two which have equal corrosion rates. No differences were found between the five sensors of one heat. Additional factors that influence the measurement are day-to-day variations of the environment in the test chamber and to some extent the position of the ACM's in the test chamber. By comparing the electrochemical and weight loss data, a cell efficiency of about 20 percent was found for copper/steel and about 7 percent for steel/steel. This low cell factor is considered to be due mainly to local cell action on individual plates and to resistance polarization in the electrolyte.

The copper/steel and steel/steel ACM's are being exposed on the Rockwell International Science Center roof for an aging period of three months, after which another series of laboratory tests will be conducted.

47. Stress Corrosion of Metals in the Atmosphere. A. Gallaccio. Extended Abstracts, International Symposium on Atmospheric Corrosion (October 5-10, 1980, Hollywood, Florida), Electrochemical Society, v. 80-2, 1980, pp. 581-582.

Attention is focused on the stress-corrosion cracking of a variety of metal alloys in atmospheric environments. Included for the various alloys

are discussions of the specificity of some atmospheric constituents associated with initiating cracking; metallurgical and processing factors bearing on cracking susceptibility; cracking of weldments, or of contiguous parent alloy; testing methods employed; practices available or applied for mitigating cracking. Commentaries are offered, as considered warranted, and as supported by the available information.

48. The Interplay of Weather, Climate, and the Durability of Materials. P. W. Brown and L. W. Masters. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 31-50.

The durability of materials is dependent, to a large extent, on the in-service environment to which they are exposed. From the standpoint of durability testing in general and assessing the resistance of a metal to atmospheric corrosion in particular, the characterization of the in-service environment is essential. The environmental factors of importance in durability testing can be divided into factors relating to: (i) weathering, (ii) biological organisms, (iii) stress, (iv) incompatibility, and (v) use. The effects of environmental factors on atmospheric corrosion are discussed with emphasis placed on weathering factors. Climatological data along with data on the abundance of pollutants are presented.

49. The Oxidation of Fe_3O_4 on Iron and Steel Surfaces. J. T. Keiser, C. W. Brown, and R. A. Heidersbach. Corrosion, v. 38, No. 7, July 1982, pp. 357-360.

Infrared and Raman spectroscopy were used to study the oxidation of Fe_3O_4 on surfaces of weathering steel, carbon steel, and pure iron. Two sets of samples were polished and coated with an Fe_3O_4 paste. One set was moistened daily with distilled water and allowed to freely dry in air. The second set was treated in a similar manner except that every other day a 0.1M Na_2SO_4 solution was used in place of the distilled water solution. In the set of samples treated only with distilled water, Fe_3O_4 was oxidized to γFeOOH on both the weathering and carbon steel surface, but oxidation of Fe_3O_4 was not observed on the pure iron surface. On all of samples treated with 0.1M Na_2SO_4 , Fe_3O_4 was oxidized initially to γFeOOH which converted to αFeOOH after several weeks. The initial oxidation of Fe_3O_4 is proposed to occur by a reaction with H_2O_2 produced from the reduction of O_2 .

50. Possibilities of Following Up Corrosion Processes in the Atmosphere by Measuring Moistening of the Surfaces. I. Jirovsky, D. Knotkova-Cermakova, I. Kokoska, and J. Prusek. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 69-82.

Corrosion threat to metals depends on the period of moistening of the surface and the aggressiveness of the surface electrolyte. The moistening period calculated from the thermodynamic parameters of the atmosphere does not agree in the first place in the case of sheltered surfaces and massive products. The QA system indicates the presence of adsorbed or phase layer

of ionic-conductive solution on the surface. The moistening period course is recorded by a continuous curve or numerically. The system was given checks at atmospheric stations and under operational conditions (the closed spaces of car bodies, the building frame works, facades). It forms part of a system of automatic collection and processing of corrosion significant data.

51. The Statistical Analysis of Atmospheric Corrosion Data. R. A. Legault and J. G. Dalal. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 285-294.

Statistical techniques for establishing the precision of a particular replicated measurement are demonstrated using atmospheric corrosion data. Establishing the reliability of a comparison is demonstrated with examples of the numerical computations necessary to the application of diagnostic tests such as the "difference of means test." Mathematical modeling is examined in some detail. Among the techniques examined are discriminant analysis, multiple regression analysis, "lack of fit" tests, determination of prediction reliability, extreme value statistics, and experimental design.

52. Theoretical Fundamentals and Engineering Principles of Atmospheric Corrosion of Metals. Y. N. Mikhailovskii. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 85-106.

The nature of atmospheric corrosion is discussed as a combination of corrosion and electrochemical processes on metals beneath absorbed and thin phase layers of electrolytes. The effects of oxygen absorption, water molecule absorption, sulfurous gas absorption, and aerosols of salts are considered. USSR work has related the observed corrosion to the parameters of the temperature-humidity and atmospheric aerochemical complex.

53. Urban-Industrial Atmospheric Corrosion of a Weathering Steel. B. R. Meybaum and E. S. Ayllon. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 415-422.

The aim of this paper was to determine the initial and propagation stages of the atmospheric corrosion of a weathering steel in urban-industrial environments. The attack would begin with the penetration of water leading to the formation of almost circular blisters. Also, pits nucleate on the surface. The propagation of these processes would produce the caves observed in cross-sections of weathering steels after long exposure periods. Thus, propagation would follow the same scheme, although the penetration is macroscopically considered uniform.

1981

1. Acid Rain: Impacts on the Natural and Human Environment. H. C. Martin. Paper No. 114, Corrosion/81 (Toronto, Canada), National Association of Corrosion Engineers, Houston, TX., April 6-10, 1981, 7 pp.

Acid Rain has been recognized as one of the most serious environmental problems of the decade. This paper reviews the current scientific assessment of the impact of acid rain on the natural environment. The costs incurred through damage to buildings and structures in North America are discussed with reference to relevant studies in Europe.

2. An American Tragedy. R. H. Boyle. Sports Illustrated, v. 55, No. 13, September 21, 1981, pp. 68-82.

Among the environmental damages attributed to acid rain are stone damage on the U.S. Capitol and the Washington Monument and corrosion damage to the Statue of Liberty.

3. Applications of an Electrochemical Accelerated Method for Testing Corrosion in the Atmosphere and in the Splash Zone. M. Pourbaix and A. Pourbaix. Metallic Corrosion, Proc. 8th Intern. Congr. Metallic Corr. (Sept. 6-11, 1981, Mainz, Fed. Rep. Germany), Dechema, Frankfurt, v. 1, 1981, pp. 305-310.

An accelerated test method for atmospheric corrosion was developed in 1966. It was used to study mechanisms of atmospheric corrosion, to compare weathering steels, copper steels and carbon steels, to develop preweathering treatments and new low-alloy steels for marine use. Attempts were made to predict the behavior of steel in the natural exposure sites, from their climatic and pollution characteristics and from results of the test method.

4. Atmospheric Corrosion of Steel in the Canadian Arctic. G. J. Biefer. Mat. Perf., v. 20, No. 1, 1981, pp. 16-19.

The first atmospheric corrosivity survey of the Canadian Arctic and sub-Arctic was performed, using mild steel wire-on-nylon bolt specimens, exposed for a period of one year. For purposes of comparison, specimens were also exposed at a number of points in southern Canada. Average rates of penetration by corrosion as low as 2 to 5 $\mu\text{m}/\text{yr}$ were recorded at ten inland sites on the mainland of the western Arctic and in the northwest Arctic Islands. However, at seven other northern sites, usually within 1 kilometer of the sea, corrosion rates of 21 to 34 $\mu\text{m}/\text{yr}$ were experienced, comparable to the rates of 22 to 30 $\mu\text{m}/\text{yr}$ recorded at seven points in southern Quebec and Ontario.

5. Corrosion Properties of Weathering Steels. D. Knotkova-Cermakova, L. Rozlivka, J. Vlckova, G. V. Akimov. Metallic Corrosion, Proc. 8th

Intern. Congr. Metallic Corr. (Sept. 6-11, 1981, Mainz, Fed. Rep. Germany), Dechema, Frankfurt, v. 2, 1981, pp. 1792-1799.

The material corrosion properties of the Atmosfix weathering steel have been deduced from the extensive station tests as well as the tests in the microclimates of the actual constructions. As a direct convertibility of the mentioned results to the corrosion behavior of steel on an object is difficult, the test program of the models of the steel girders and individual frames with the samples was realized direct on the selected steel constructions. The systematical investigation of the corrosion effects on the selected objects was connected with the ultrasonic measurement of the element wall thickenesses and corrosion tests of a special arrangement taking the specific character of the concerned objects into account. The new method of the rust layer compactness evaluation proved to be very helpful.

6. Determination of Atmospheric Corrosion Kinetics by an Electrochemical Method. J. A. Gonzalez, J. M. Bastidas and S. Feliu. Metallic Corrosion, Proc. 8th Intern. Congr. Metallic Corr. (Sept. 6-11, 1981, Mainz, Fed. Rep. Germany), Dechema, Frankfurt, v. 1, 1981, pp. 311-316.

Corrosion values calculated from polarization resistance measurements are compared with those from gravimetric data, for mild steel and zinc subjected to a variety of laboratory and natural exposure conditions. It is concluded that atmospheric corrosion predictions carried out by the electrochemical method proposed provided a high degree of reliability. The sensitivity of the method is such that it is not only applicable to a fairly corrodible material, such as Fe, but also to a much more resistant material, such as Zn. The instantaneous response of the multilamellar cells used permits knowing what is happening during the initial moments and at any stage of the corrosion process.

7. Determination of the Corrosivity of Atmospheres With Electrochemical Techniques. F. Mansfeld. Extended Abstracts, Fall Meeting, Electrochemical Society, Denver, CO, v. 81-2, October 11-16, 1981, pp. 444-445.

The atmospheric corrosion process is of discontinuous nature with corrosion occurring only during the time-of-wetness (t_w). The total corrosion loss M during a certain exposure period can be expressed as:

$$M = \sum_{i=1}^n r_i t_{w,i}$$

where r_i is the corrosion rate during the i -th time-of-wetness. In order to fully characterize the corrosion behavior, it is therefore necessary to determine r_i , $t_{w,i}$ and the frequency n of the time-

of-wetness periods during exposure. Such measurements can be performed using electrochemical techniques.

Time-of-wetness (t_w) can be determined with electrochemical sensors which give a comparison of the output of a Cu/zinc atmospheric corrosion monitor (ACM) in the form of galvanic current i_g , the relative humidity (RH) and temperature T recorded at the same site for one week. From the i_g -time curves t_w has been determined as the time for which the background current of the ACM is exceeded. In addition, the corrosion time t_{corr} for which $i_g > 1.0 \mu A$ (corresponding to a corrosion rate for zinc in excess of $3 \mu m/year$) and the ratio $\alpha = t_{corr}/t_w$ have been determined. These three parameters are used to characterize the corrosivity of different test sites and/or to determine the changes of corrosivity with time.

The corrosion rate of the anode material in an ACM, which can be calculated by integration of the current-time curve, can also be used to determine the corrosivity of a test site. Comparisons of integrated cell current Q and weight loss data in outdoor exposure and laboratory studies have shown that in the case of steel the electrochemical sensors measure only about 20% of the corrosion rate as determined by weight loss. The author has investigated the probable causes of these deviations in a statistically designed experiment. It was found that the particular heat of the sensor material, the aging process in outdoor exposure, the microclimate on different material surfaces, the conductivity of surface electrolytes, the sensor design and probably other factors all can influence the sensor output and its correlation with weight loss.

While the use of electrochemical sensors undoubtedly has increased the possibilities for developing a better understanding of atmospheric corrosion processes and allows to establish criteria for determining the corrosivity of atmosphere, more work needs to be done to develop these sensors into instruments which can be used to obtain quantitative data.

8. Effects of Environmental Factors on Atmospheric Corrosion of Carbon Steel in Niigata (Japan). F. Katoh, S. Yasukawa, H. Nishimura and M. Yasuda. Boshoku Gijutsu, v. 30, No. 6, 1981, pp. 337-343 (Japanese).*

To investigate the effects of environmental factors on the atmospheric corrosion of carbon steel, the corrosion rate and the amount of chemical pollutants in the atmosphere were determined and the data of some meteorological elements were obtained for 4 yr. Strong positive correlations were found between the amounts of chloride, sulfate, and SO_2 and the corrosion rate. Strong negative correlations were found between the air temperature, duration of sunshine, and solar radiation, and the corrosion rate.

9. Evaluation of Electrochemical Techniques for Monitoring of Atmospheric Corrosion Phenomena. F. Mansfeld. Electrochemical Corrosion Testing, ASTM STP 727, edited by F. Mansfeld and U. Bertocci, American Society for Testing and Materials, 1981, pp. 215-237.

A review is presented of past and present efforts to use electrochemical techniques to evaluate basic phenomena of atmospheric corrosion, measure time-of-wetness, and perform corrosion-rate

measurements in outdoor exposure. This is followed by a summary of recent work carried out in the author's laboratory. Time-of-wetness measurements have been carried out continuously over a three-year period at the same location using copper/steel and copper/zinc sensors. An analysis of the monthly distribution of relative humidity and corrosion rates determined with the same sensors has resulted in correlations between them. Weight-loss measurements under thin layers of electrolytes that are drying at RH < 100 percent have shown that, in most cases, corrosion rates are much higher under these conditions than in bulk solutions. Electrochemical measurements carried out under identical conditions show the continuous increase of corrosion rates during the drying period. A comparison of corrosion rates determined by weight loss and electrochemical techniques under thin layers of electrolytes indicates that the electrochemical data underestimate the true corrosion rates. The determination of cell factors based on weight-loss data is one approach for using the electrochemical technique in a more quantitative manner.

10. Factors Affecting the Atmospheric Corrosion of Steel. B. R. Meybaum, E. S. Ayllon, R. T. Bonard, S. L. Granese and J. L. Ikeha. *Metallic Corrosion*, Proc. 8th. Intern Congr. Metallic Corr. (Sept. 6-11, 1981, Mainz, Fed. Rep. Germany), Dechema, Frankfurt, v. 1, 1981, pp. 317-335.

The purpose of this paper was to determine the influence of the morphological and chemical characteristics of the rusts developed on different steels upon their corrosion rates, when they are submitted to atmospheric corrosion in four distinct environmental conditions. The influence of the rolling process on the initiation and growth of the rusts was analyzed. SEM and optical microscopy in connection with EPMA were used. The analysis by means of IR spectroscopy and x-ray diffraction of the prepared samples of pure α , β , γ and δ FeOOH and of magnetite was applied to the characterization of the rusts in which these iron compounds are generally informed to be present. An electrochemical spectroscopy of these substances was intended to test the results of the analysis of the natural rust, through the characteristic curve obtained for the reduction of each of them.

11. Poland - The Most Polluted Country in the World. L. Timberlake. *New Scientist*, v. 92, No. 1276, October 22, 1981, pp. 248-250.

In Poland's Katowice region, the nation's industrial heartland and source of most of its steel and coal, the sulfuric acid and nitric acids which fall with each rain have so corroded the railway tracks that trains are not allowed to go more than 40 km per hour. Much of Katowice's pollution is blown by the prevailing winds 70 km east to the City of Cracow, where it falls in the form of acid rain and where the destruction it causes is likely to have international repercussions. The city is a unique architectural embellishment. The faces of important stone statues at Wawel Castle have crumbled. Steeples fall off churches; balconies must be constantly replaced and repaired; the view down every narrow street is disrupted by the scaffolding of workers trying to hold the buildings together.

Acid rain dissolved so much of the gold roof of the 16th century Sigismund Chapel of Wawel Cathedral that it recently had to be replaced. Something not unlike aqua regia falls daily in the Cracow rains, and converted the chapel's original gold roof into soluble chlorides.

12. Practical Experience with an Electrochemical Technique for Atmospheric Corrosion Monitoring. V. Kucera and J. Gullman. Electrochemical Corrosion Testing, ASTM STP 727, edited by F. Mansfeld and U. Bertocci, American Society for Testing and Materials, 1981, pp. 238-255.

An electrochemical technique based on integration of the current in electrolytic cells with an external impressed voltage has been used in various investigations. Cells that permit measurements extending over several years without risk of short-circuiting by corrosion products have been developed. The electronic integrator has been proved to function reliably during all measurements. Even if the electrochemical background of the technique is not well defined, a relation has been found to exist between the cell current and the corrosion rate. The relation is fairly constant in measurements at one site, but depends to some extent on the degree of pollution, which is a serious limitation. The technique appears, however, to be well suited for comparative studies of different alloys and the protective effect of corrosion products, and for studies of copper and zinc in run-off from building structures. The time of wetness measured by the technique may be of interest in the study of the influence of climatic factors.

13. Preweathered Zinc for Roofing. M. Leclercq. Metallic Corrosion, Proc. 8th. Intern. Congr. Metallic Corr. (Sept. 6-11, 1981, Mainz, Fed. Rep. Germany), Dechema, Frankfurt, v. 1, 1981, pp. 299-304.

Preweathered zinc is now available in the form of strips in coils and in sheets both of which, from the point of view of handling and of working the metal as well as satisfying esthetical purposes, fully answer the requirements of roofing. It is obtained by a continuous process, being the result of a chemical conversion treatment of the metallic zinc strip by chemical and/or mechanical pretreatment, conversion by a phosphatizing treatment and the application of a temporary protective film.

The converted zinc surface exhibits a uniform dark gray color and its whole surface is covered with a continuous and tightly adhering layer of zinc phosphate crystals, which is responsible for its excellent behaviour under conditions of mechanical deformation and atmospheric oxidation.

Thus, the many advantages of this new product are:

- 1) the shiny metallic appearance is disposed of during the first few months of exposure;
- 2) the dark gray colour is harmonious to that of other materials generally used for roofing purposes in our region of the world;
- 3) the resistance of the zinc to oxidation is enhanced as a result of the presence of a conversion phosphate coating.

A study of this coating has been made dealing with its properties and its behaviour under exposure to accelerated and field testing.

14. Some Aspects of Nature of Sulphur Dioxide Accelerated Atmospheric Corrosion of Iron. D. J. Spedding and A. J. Sprott. *Metallic Corrosion, Proc. 8th. Intern. Congr. Metallic Corr.* (Sept. 6-11, 1981, Mainz, Fed. Rep. Germany), Dechema, Frankfurt, v. 1, 1981, pp. 329-335.

The nature of the sites of discrete adsorption of sulphur dioxide on a clean iron surface has been investigated. Studies of the oxides and oxyhydroxides of iron likely to be on the surface of iron exposed to the ambient atmosphere indicated high sulphur dioxide uptake on $\gamma\text{-Fe}_2\text{O}_3$. In addition, the sorbed sulphur dioxide on $\gamma\text{-Fe}_2\text{O}_3$ was irreversibly bound, while that on $\alpha\text{-FeOOH}$ (a major surface component of the iron) was reversibly bound. It is proposed that points of high sulphur dioxide uptake on iron are due to the presence of $\gamma\text{-Fe}_2\text{O}_3$ in a surface film that is predominantly $\alpha\text{-FeOOH}$. Sulphate formed from sulphur dioxide at high uptake points probably initiate the formation of sulphate nests and thus active corrosion.

The dependence of the mass of sulphur dioxide sorbed by an iron surface on the relative humidity of the surrounding atmosphere was also investigated. It was found that there was no clear relationship between the mass of water at a given relative humidity on the iron surface and the mass of sulphur dioxide sorbed. It is proposed that interactions of sulphur dioxide with water vapor prior to adsorption may explain the above observations.

15. The Consideration of the Microclimate Effect on the Characteristic of Atmospheric Environments and Corrosion of Metals. D. Knotkova-Cermakova, P. Holler, J. Vlckova. *Metallic Corrosion, Proc. 8th. Intern. Congr. Metallic Corr.* (Sept. 6-11, 1981, Mainz, Fed. Rep. Germany), Dechema, Frankfurt, v. 1, 1981, p. 337.

During the recent 10 years a high number of experimental results have been collected, in the department of atmospheric corrosion of the State Research Institute of Material Protection, on the corrosion of metals and data on the characteristics of the atmospheric environment for the standard environments of the typical outdoor shed and indoor types as well as for various microclimates.

The statistical processing of the long-time climate characteristics with the view to the atmospheric corrosion of metals and the dividing of the Czechoslovak territory into the individual regions has been carried out. The investigation of the corrosion aggressive distribution in the selected regions as well as in the territory of Czechoslovakia as a unit, has been carried out, too.

The results have been analyzed with the view of the basic indices of the corrosion aggressivity of atmospheres and the utilizability of the common criterions for the actual exploitation microclimates has been considered. The knowledge had been utilized for the generalization conducive to the proposals of the atmospheric corrosivity classification for the standardization within the framework of the CEMA and ISO.

16. The Effect of Phase Composition on Corrosion Behaviour on Ion-nitriding Layers. A. E. Varhoshkov and I. A. Bedloev. *Metallic Corrosion, Proc. 8th. Intern. Congr. Metallic Corr.* (Sept. 6-11, 1981, Mainz, Fed. Rep. Germany), Dechema, Frankfurt, v. 2 1981, pp. 1086-1092.

In recent years the ion-nitriding technology has achieved considerable progress. One of the main contributions of the process is the possibility it offers in producing nitrided layers of a definite phase composition. The aim of the experiments was to assess the functional relationship between the structure of the nitride layers and their corrosion characteristics in different types of electrolytes. The phase composition of the diffusion layers has been determined by metallographic and X-ray analysis. Electrochemical procedures based on the cathodic and anodic polarization curves were used to study the corrosion behaviour of the different ion-nitrided layers. Nitriding sponsors the increase of corrosion resistance in neutral electrolytes. A greater corrosion resistance is observed in biphasic ($\epsilon + \gamma$) nitride layers.

17. The Mechanism of Corrosion of Mild Steel by Elemental Sulphur/Water Suspensions. S. B. Maldonado and P. J. Boden. *Metallic Corrosion, Proc. 8th. Intern. Congr. Metallic Corr.* (Sept. 6-11, Mainz, Fed. Rep. Germany), Dechema, Frankfurt, v. 1, 1981, pp. 338-343.

Elemental sulphur suspended in demineralized water undergoes hydrolysis to form H_2SO_4 and H_2S and this reduces the pH. Rapid corrosion of mild steel is caused by the continuous replacement of hydrogen ions (from sulphur/water hydrolysis) as those are consumed by the cathode reaction. This study gives quantitative data on this hydrolysis and also gives information on the breakdown of well-formed passive films on mild steel in 0.1 M NaOH as a result of HS^- ions. Breakdown potentials have been determined below which corrosion by sulphur is prevented. This potential may, however, be sufficiently negative (approx. -0.8-1.0 V vs SCE) to cause hydrogen embrittlement.

1980

1. A Model of Atmospheric Corrosion of Metals Allowing for Meteorological and Aerochemical Characteristics. Y. N. Mikhailovskii, P. V. Strekalov, and V. V. Agafonov. *Protection of Metals*, v. 16, No. 4, 1980, pp. 308-323.

The authors discuss a physicochemical model and a corresponding mathematical representation of the processes of atmospheric corrosion of metals in relation to time, air humidity and temperature, and the concentrations of sulfur dioxide and chlorides in the atmosphere. On the basis of data obtained from the seven corrosion stations of the European member-nations of the Council for Mutual Economic Aid, they determine the parameters necessary for predicting the atmospheric corrosion of metals. They calculate the probable rates of atmospheric corrosion of steel, zinc, copper, aluminum, and magnesium alloys in the open air and in a semiclosed atmosphere. The error of the model calculations does not exceed 18-21%.

2. A Review of Air Pollutant Damage to Materials. J. E. Yocum and A. R. Stankunas. Draft Report to Environmental Criteria and Assessment Office, Office of Research and Development, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, December 1980, 92 pp.

The presence of air pollutants, notably sulfur oxides, particulate matter, nitrogen oxides, and ozone under the proper circumstances can exacerbate damage to non-living materials thereby producing costs to society. The types of damage that can be caused by air pollution are summarized. Problems in quantifying the extent of damage to materials of specific pollutants are: (1) The types of damage associated with air pollutants tend to occur in unpolluted atmospheres and cannot be distinguished from those caused or enhanced by the presence of air pollutants. Damage can be produced by moisture, CO₂, natural particulate matter, sunlight, and other features of the natural environment. Thus, determining the isolated influence of a given pollutant in an ambient exposure situation is not a straightforward process. (2) Laboratory studies where individual pollutants are introduced to sensitive materials in known exposures independent of other influences tend to be operated at unrealistically high concentrations and otherwise are not representative of real life exposure situations. (3) Reduction in ambient levels of pollutants such as SO₂ as the result of air pollution control efforts has significantly reduced the exposure and degree of possible damage to exposed materials. Damage identified and measured today may have been the result of much earlier exposure when concentrations were much higher. (4) Changes over recent years in the types of materials and protective coatings exposed to the atmosphere as a result of technological improvements in materials is having a fundamental effect upon the nature and extent of air pollution-induced damage to materials and associated damage costs. (5) Determination of the quantities of materials in place in relation to air pollutant exposures is a difficult task, especially when significant amounts of certain materials (for example, fabrics, paints, and paper) may be exposed to indoor environments or other locations not represented by typical ambient monitors.

Society is faced with the difficult task of balancing the benefits it may gain by reductions in pollution levels against the economic and social costs of obtaining those reductions. Unfortunately, the current ability of society to accurately relate the costs of damage to materials to the level of ambient pollution is poor. The existing state-of-the art for employing economic damage functions in rational decision-making is such that only crude, qualitative use of such results is appropriate. Type of economic damage, methods for calculating economic impact on material damage, and specific economic damage functions are discussed.

3. Atmospheric Corrosion Resistance of Steels Prepared From the Magnetic Fraction of Urban Refuse. S. D. Cramer, J. P. Carter, and B. S. Covino, Jr. U.S. Bureau of Mines RI 8447, 1980, 32 pp.

The Bureau of Mines conducted a corrosion study in which the magnetic fraction of urban refuse was used as melting stock in the preparation of high-strength low-alloy and carbon steel. Samples of these alloys and those of comparable commercial-grade steels were exposed to industrial,

rural, and marine environments. This paper presents the results of 0.5, 1.0, 1.5, and 3.8 years exposure. The use of the magnetic fraction of urban refuse as melting stock increased the atmospheric corrosion resistance of carbon steel by 25 percent. Increasing sulfur (from the atmosphere) in the corrosion film resulted in increased corrosion resistance. The residual elements in the steel most responsible for improving corrosion resistance were copper and tin.

4. Background and Principles of Long-Term Performance of Building Materials. S. E. Pihlajavaara. Durability of Building Materials and Components, ASTM STP 691, edited by P. J. Sereda and G. G. Litvan, American Society for Testing and Materials, 1980, pp. 5-16.

A review is presented of historical background information, service life expectations and the need for research in the field of the durability of materials. The necessary procedures and intervals of the maintenance of some building materials also are examined. Information on the performance of materials should be expressed clearly in terms of service years dependent on degradation factors, of degradation effects during lifetime, and of maintenance procedures and intervals.

5. Characterization of Atmospheric Corrosion Products on Weathering Steels. B. R. Meybaum and E. S. Ayllon. Corrosion, v. 36, no. 7, July 1980, pp. 345-347.

Microalloyed steels show a greater atmospheric corrosion resistance than plain carbon steels through the formation of protective films, designated as patinas. During the development of these films, they present a continuous double layer structure. The inner phase is the only one left after long exposure periods and determines the low atmospheric corrosion rates observed. In the present work a new technique was applied for the separation of phases. Characterization of two phase films and of the inner phase alone was performed by IR analysis, electrochemical reduction, and scanning electron microscopy. Test pieces of a weathering steel (C, 0.11; Mn, 0.38; Si, 0.23; P, 0.9; Cr, 0.69; Ni, 0.11; and Cu, 0.38) were exposed for 9 and 22 months at a semi-industrial atmosphere. Characterization techniques, applied to samples of two phase films and of the inner phase, showed little difference in composition. However, morphological differences suggest on the contrary, greater barrier effect due to the inner phase rather than the outer one.

6. Colloid Chemical Aspects of Corrosion of Metals. E. Matijevic. Pure Appl. Chem., v. 52, 1980, pp. 1179-1193.

The corrosion of metals and alloys results in the formation of soluble hydroxylated complexes and precipitated metal hydrous oxides, with the end-products almost invariably in colloidal state as films, particles, or aggregates. It is, therefore, obvious that in the course of the corrosion process the materials undergo chemical and morphological changes. Even if precipitation does not occur, the solution adjacent to

the metal surface will have an entirely different composition than the bulk liquid phase.

Little proven information is available on the chemical mechanism of the processes involved in the precipitation of metal (hydrous) oxides. This is, in part, due to the complexity of reactions involved in the solid phase formation and to the sensitivity of precipitation processes to various parameters, making it difficult to reproduce a given material.

Recently, it was possible to develop well defined colloidal metal hydrous oxides which can serve as models for corrosion products. These systems consist of particles uniform in chemical composition, size, and shape, that can be repeatedly generated under reproducible conditions. The so prepared "monodispersed" sols are used to elucidate the chemical mechanism of metal corrosion processes, to study the properties of the model corrosion products (surface, electric, magnetic, optical, etc.), to investigate their interaction with various additives (chelating agents, etc.), and, finally, to establish factors governing their adhesion or their detachment from different substrates.

Examples of these model dispersions are shown and various studies relevant to corrosion of metals in general and of iron in particular, carried out with such materials, are discussed.

7. Corrosion of Metal in Wood Products. A. J. Baker. Durability of Building Materials and Components, ASTM STP 691, edited by P. J. Sereda and G. G. Litvan, American Society for Testing and Materials, 1980, pp. 981-993.

A description is given of the source of metal corrosion products that cause wood deterioration around corroding metal in wet wood. Corrosion of isolated steel fasteners in wood and the formation of acid conditions around the corroding steel is explained in terms of "crevice corrosion." The source of acid and alkaline conditions around corroding metals undergoing galvanic corrosion and the source of alkaline conditions around cathodically protected metal also are explained.

Results of a 3-year corrosion test of eleven wood fastener materials in wood treated with copper-containing waterborne salt preservatives indicate that, when long service life is required under wet conditions, fastener materials that are cathodic with respect to copper should be chosen. The literature indicates that metals in contact with fire retardant-treated lumber and cellulose insulation under high moisture conditions also may be subject to corrosion.

8. Critical Review of the Available Physicochemical Material Damage Functions of Air Pollution. M. Benarie. Report No. EUR-6643, Commission on the European Communities, 1980, 97 pp.

The effect of air pollution damage of materials with special emphasis on the theory of damage functions, both from engineering and economic points of view is reviewed. The damage of metals, coating materials, construction materials, and fabrics are discussed.

9. Durability of Materials and Construction. J. H. Keyser. Durability of Building Materials and Components, ASTM STP 691, edited by P. J. Sereda

and G. G. Litvan, American Society for Testing and Materials, 1980, pp. 38-55.

In this paper, the author emphasizes the need to use a systems approach to solve complex durability problems and to incorporate a durability subsystem within the quality assurance system. The purpose of this approach is to continuously improve design, specifications, construction and maintenance.

Based on case histories of performance of sidewalks, pavements, and elevated structures, the author discusses problems linked with a few elements of such a subsystem and concludes on the need to develop design methods for durability, realistic specifications, meaningful durability tests, and rational methods for assessment of durability. Furthermore, the need to integrate the activities of all quality responsible agencies into a single managerial effective quality assurance system is stressed.

10. Durability of Some Common Building Materials. W. H. Gutt and L. H. Everett. Durability of Building Materials and Components, ASTM STP 691, edited by P. J. Sereda and G. G. Litvan, American Society for Testing and Materials, 1980, pp. 131-144.

In this paper the durability of some materials used in building is considered; in particular, concrete, fibrous composites, surface coatings, and adhesives. For each of these materials the processes which cause change in the physical, mechanical, or chemical properties are discussed and the deterioration which occurs on aging is reviewed, identifying, where appropriate, the specific environments producing unacceptable loss of function or appearance. Careful selection of the material used in specific applications is considered to be a prime requirement for continued good service and low maintenance.

11. Indoor Corrosion of Metals. D. W. Rice, R. J. Cappell, W. Kinsolving, and J. J. Laskowski. J. Electrochem. Soc., v. 127, No. 4, 1980, pp. 891-901.

The indoor corrosion rates of Cu, Ag, Ni, Co, and Fe were measured at eight locations in the United States. Concurrent pollutant and relative humidity measurements were also made at six sites. The rates are shown to be log-normally distributed over the sample population. A statistical comparison of outdoor and indoor rates shows that silver corrodes approximately the same both indoors and outdoors. Copper and nickel corrode 100 times faster outdoors, and iron corrodes 2,000 times faster outdoors. The corrosion rate sensitivity to relative humidity is speculated to explain these differences. Pollutant concentrations are shown to be generally attenuated indoors except for NH_3 and reduced forms of sulfur. The indoor corrosion rates of copper and silver are reasonably well correlated to the measured reduced sulfur concentrations. Nickel rates correlate best to the acid chlorine containing gases.

12. Influence of Sulfur Dioxide, Periodical Wetting and Corrosion Products on the Atmospheric Corrosion of Steel. R. Ericsson and T. Sydberger. *Werkst. Korros.*, v. 31, No. 6, 1980, pp. 455-463.*

Results from lab. atm. corrosion test on samples of a C- and a low-alloy steel, with and without pre-exposure (1, 3, and 12 mo.) in an outdoor atm. are reported. The lab. exposure was performed in SO₂-containing (0.4 µg SO₂/cm²-h) and SO₂-free atmospheres at 90% relative humidity and 22°. The influence of atm. SO₂ on the instantaneous corrosion rate markedly decreases with increasing pre-exposure. Comparisons of corrosion-rates calculated from outdoor and laboratory exposure tests with and without periodical wettings show that the atm. corrosion proceeds during or following the periods of atm. precipitation or condensation, i.e., under conditions of an apparently wet rust layer. A synergistic effect of SO₂ and periodical wetting was established. Due to the leaching of sulfate ions from the rust layer, immersion sequences (to simulate rainfall) resulted in lower corrosion rates than the simulation of dew by short spraying sequences. The corrosion of pre-exposed samples could be related to the amount of sulfate leached from the rust during immersions.

13. Laboratory Studies of Atmospheric Corrosion--I. Weight Loss and Electrochemical Measurements. F. Mansfeld and S. Tsai. *Corrosion Science*, v. 20, 1980, pp. 853-872.

Electrochemical studies have been performed with the atmospheric corrosion monitor (ACM) under thin layers of electrolyte which were drying out at relative humidity (RH) < 100 percent. Galvanic couples (copper/steel, copper/zinc) and one-metal (steel, zinc) ACMs were used. Measurements were carried out as a function of RH and Na₂SO₄ concentration. In addition, weight loss data were collected under identical conditions in thin layer experiments for steel and zinc in 0.01 N solutions of NaCl, Na₂SO₄, HCl, H₂SO₄ and distilled water in air, air + 1 ppm SO₂, Ar and Ar + 1 ppm SO₂. The data obtained in air and air + SO₂ were compared to weight loss results in bulk solutions.

The electrochemical technique makes it possible to follow the changes of corrosion rates with time. As observed in outdoor exposure, a large increase of corrosion rates occurs when the electrolyte layers become very thin, shortly before the surface dries out. These findings explain the results of the weight-loss data which show, for most environments, a much larger corrosion rate than in the bulk electrolyte. An accelerating effect of sulfur dioxide was observed for steel at higher RH values, while for zinc, no effect occurred in NaCl, Na₂SO₄, and H₂SO₄, but an inhibiting effect was measured in HCl and in distilled H₂O.

Since weight loss and electrochemical data were recorded under identical conditions, it is possible to determine how accurately the ACM data reflect the true corrosion rate. It was found for copper/steel ACMs that the electrochemical data follow the same trends as the weight-loss data, but account for only about 20 percent of the corrosion rate. Due to larger scatter in the weight-loss data, a similar efficiency factor could not be determined for copper/zinc. For steel and zinc ACMs, the true Tafel slopes are not known, which makes a calculation of corrosion rates

doubtful. The low cell efficiency is considered to be due to local corrosion of single cell plates and to IR-drop effects.

Despite the fact that exact corrosion rates cannot, at present, be obtained from ACM data, the technique appears very valuable for following the changes of atmospheric corrosion behavior and for time-of-wetness measurements.

14. Metals in America's Historic Buildings. M. Gayle, D. W. Look, and J. G. Waite. U.S. Department of the Interior, Heritage Conservation and Recreation Service, Washington, D.C., 1980, 170 pp.

Part I of this report presents short illustrated surveys of the architectural metals most often used in American buildings and other architectural features such as sculpture, fountains, and "street furniture". The photographs document common uses of metals such as copper roofing, zinc statuary, cast-iron storefronts. Part II examines the questions of how architectural metals deteriorate, and concentrates on the techniques available to architects and conservators in preserving and maintaining the metal components.

15. Nature of Atmospheric Rust on Iron. I. Suzuki, Y. Hisamatsu, and N. Masuko. J. Electrochem. Soc., v. 127, No. 10, 1980, pp. 2210-2215.

In order to elucidate the mechanism of self-protection of weathering steel, the physical, chemical, and electrochemical nature of rust was studied with special attention to the effect of copper addition. The aggregating state of the rust layer is influenced by two factors: the time of exposure and beneficial elements added to the steel. Copper additions inhibit the growth of the primary colloidal particles. This action of copper has an effect on the properties of rust and serves to increase the protective ability of the rust layer.

16. Pacer Lime: An Environmental Corrosion Severity Classification System. R. Summit and F. T. Fink. AFWAL-TR-80-4102 (Part 1), Wright Aeronautical Laboratories, Wright-Patterson AFB, Ohio, August 1980, 121 pp.

A system has been developed for rating the corrosivity of aircraft operational environments. This system takes account of weather, atmospheric pollutant, and geographic factors to compute a severity index for three aspects of corrosion maintenance: aircraft washing, repainting, and repair needs. Computed ratings are in good agreement with aircraft corrosion experience and atmospheric testing programs at several locations.

17. Pacer Lime: Experimental Determination of Environmental Corrosion Severity. R. Summit and F. T. Fink. AFWAL-TR-80-4102 (Part 2), Wright Aeronautical Laboratories, Wright-Patterson AFB, Ohio, June 1980, 28 pp.

Atmospheric exposure of aircraft alloys was conducted to provide experimental data in support of an environmental rating system. Alloys tested were magnesium AZ31B, 4340 steel, aluminum 2024-T3, 7075-T6 Alclad, 7079-T6 Alclad, and titanium-6Al-4V. Test sites were nine in the continental U.S., one in Hawaii, and one in England. Measured corrosion rates are in good agreement with literature values and USAF corrosion maintenance experience.

18. Regional Air Pollution Study: Effects of Airborne Sulfur Pollutants on Materials. F. Mansfeld. NTIS Report PB81-126351, January 1980, 163 pp.

Samples of galvanized steel, weathering steel, silver, marble, nylon and two types of house paint and stress samples of Al 2014 and 7079 were exposed at nine sites of the Regional Air Monitoring System in the St. Louis area. Wind speed and direction, temperature, dew point, total sulfur, SO₂, H₂S, O₃, NO_x, total hydrocarbons, total suspended particulate matter, sulfate and nitrate were recorded.

For galvanized steel a pronounced effect of time of first exposure was observed. The corrosion behavior of weathering steel was not seasonally dependent. House paint showed discontinuous erosive behavior. Exposure to the south was more erosive than exposure to the north. Rates for latex paint were higher than for oil based paint. The erosion rate of marble decreased with time. At some sites 50% reflectance loss of silver occurred after 3 months exposure. All samples of Al 7079 at 25 Ksi failed in less than 255 days, while complete failure at 15 Ksi occurred between 277 and 630 days. For Al 2014 more scatter was observed.

The pollution levels in St. Louis were found to be rather low. Ozone showed similar seasonal changes as the temperature. Sites close to the center of St. Louis had lower ozone but higher NO_x and total hydrocarbon levels. Sulfate was about twice as high in summer as in winter. A first attempt at multiple regression analysis was made. Apparent inconsistencies in the estimated effects are believed to be due to multi-collinearity.

19. The Meaning of Durability and Durability Prediction. G. Frohnsdorff and L. W. Masters. Durability of Building Materials and Components, ASTM STP 691, edited by P. J. Sereda and G. G. Litvan, American Society for Testing and Materials, 1980, pp. 17-30.

The concept of durability is not well defined. The term durability is often used to imply the possession of qualities associated with long life. In some standards for building components, it is nonquantitative and implies that design requirements are likely to be exceeded for the design service life or some other specified period. The new ASTM Recommended Practice for Developing Short-Term Accelerated Tests for Prediction of the Service Life of Building Components and Materials (E 362 - 78), is outlined. The application of the recommended practice to service life prediction is illustrated by an example for work being planned on protective coatings for steel.

1979

1. Atmospheric Corrosion of Metallic Systems. II. Analysis of the Corrosiveness of a Medium at Atmospheric Testing Stations of Comecon Countries Based on the Results of Five-Year Tests on Steel, Zinc, Copper and Aluminum. K. Barton, D. Knotkova-Cermakova, P. V. Strekalov, V. S. Kemkhadze, V. Kozhukharov, and A. Szobor. Zashch. Met., v. 15, No. 4, 1979, pp. 408-415 (Russian).*

The results of 5 year corrosion tests are outlined for steel, Zn, Cu, and Al in rural, industrial, and marine atmospheres. A comparative evaluation of the corrosiveness of various atmospheres is made on the basis of the annual duration of wetting of the metal surface and the content of SO₂ and Cl in the atmosphere.

2. Atmospheric Corrosion of Steels Prepared From the Magnetic Fraction of Urban Refuse. S. D. Cramer, J. P. Carter, and B. S. Covino, Jr. Resource Recovery and Conservation, v. 4, 1979, pp. 141-159.

The magnetic fraction of urban refuse was used as melting stock in the preparation of a high-strength, low alloy (HSLA) steel and a carbon steel. Product steels were made from incinerated steel can scrap, nonincinerated-nondetinned steel can scrap, nonincinerated-detinned steel can scrap, and dilutions of these scraps with No. 1 heavy melting scrap. In continuing tests, 101x152x3 mm panels of the product steels were exposed to industrial, rural, and marine environments to determine their atmospheric corrosion properties. Panels of the respective commercial steels were exposed at the same time to establish baseline data for the test sites.

Weight-loss data are reported for atmospheric exposures of 0.5, 1.0, 1.5, and 3.8 years. The marine environment was the most corrosive; the industrial environment was the least corrosive. The atmospheric corrosion resistance of the carbon steel was improved 25 percent by using incinerated scrap and nonincinerated-nondetinned scrap in the steelmaking process. In no case was the atmospheric corrosion resistance of the carbon steel degraded by using the magnetic fraction of urban refuse as melting stock.

The residual elements responsible for improving the corrosion resistance of the carbon steel were identified as tin and copper. At the levels present in the product steels, Cr, Ni, and Pb had no observable effect of the corrosion resistance of either the HSLA steel or the carbon steel.

3. Atmospheric Corrosion Rates, Time-Of-Wetness and Relative Humidity. F. Mansfeld. Werkst. Korros., v. 30, No. 1, 1979, pp. 38-42.*

The effect of relative humidity (RH) on the atmospheric corrosion rates was studied in laboratory experiments for rust covered steel in air and air + 1 ppm SO₂. While a large effect of NaCl impurities in rust was found, no effect of SO₂ was observed. Time-of-wetness was determined in outdoor exposure by an atmospheric corrosion monitor, and it was found

that the time-of-wetness corresponded to RH > 40 percent in Thousand Oaks, California.

4. Corrosion - Metals Reactions to Achieve Stability. III. Combating Atmospheric Corrosion. H. E. Trout. Industrial Heating, v. 46, No. 8, August 1979, pp. 30-31.

The overall effects of atmospheric corrosion are the results of a number of interrelated factors acting upon the metal. These factors include moisture in the air, temperature, impurities in the air (SO₂, Cl, and particles) and metal chemistry. The paper discusses these aspects of atmospheric corrosion as they affect steels.

5. Electrochemical Properties of Iron Rust. I. Suzuki, N. Masuko, and Y. Hisamatsu. Corrosion Sci., v. 19, 1979, pp. 521-535.

In order to elucidate the electrochemical properties of iron rust, galvanostatic cathodic polarization of rusted steel and rust electrodes, prepared by fixing a piece of rust plate on an acrylic plate with conductive adhesive, was examined. The change in the amount of crystalline substances in the rust layer was observed by X-ray diffraction. The electrochemically active intermediate substances could not be identified by X-ray diffraction, but their behavior was distinguished from that of crystalline substances. The rest potential of the rust electrode was controlled by the equilibrium potential of intermediate substances. "An overlapping dual electrode" model is proposed for rusted steel in aqueous solution. Beneficial elements added to weathering steel inhibit the formation of crystalline magnetite in the cathodic reduction process of rust and increase the electrical resistance of the rust layer.

6. Electrochemical Studies of Atmospheric Corrosion. F. B. Mansfeld. NTIS Report AD-A063922, January 1979, 135 pp.

Electrochemical studies of atmospheric corrosion phenomena have been performed over a 42 month period. The kinetics of corrosion reactions occurring under thin electrolyte layers (100-1,000 μ m) have been studied for steel, Zn, Cu and Al by recording potentiodynamic polarization curves using a modified atmospheric corrosion monitor (ACM). Normal Tafel behavior was observed. The limiting current for oxygen reduction increased linearly with inverse film thickness. Similar experiments in which corrosion kinetics were determined from polarization resistance measurements using the CORFIT computer program showed that with decreasing film thickness the corrosion reaction becomes charge transfer controlled. Laboratory and outdoor exposure tests have shown that corrosion rates increase drastically when the electrolyte layers become very thin during the drying out process at relative humidity (RH) < 100 percent. This phenomenon has been studied in detail by evaluating the effects of corrosion product chemistry, RH and SO₂. A comparison of corrosion rates obtained under identical conditions in weight-loss and electrochemical experiments has been carried out for steel and zinc as a function

of RH and electrolyte concentration. The ACM's have been used extensively to monitor atmospheric corrosion behavior in outdoor exposure. In the final phase of this project surface analyses have been carried out for 4130 steel and zinc which had been corroding under thin electrolyte layers.

7. Results of 30 Months Atmospheric Corrosion Testing in St. Louis, MO, U.S.A. F. Mansfeld. Reliability of Materials for Solar Energy--Workshop Proceedings, CONF-781228, v. 2, Pt. 1, October 1979, pp. 627-657.

Samples of galvanized steel, weathering steel, silver, marble, and two types of house paint and stress samples of Al 2014 and 7079 have been exposed for various lengths of time. Atmospheric data which include wind speed and direction, temperature, relative humidity, total S, SO_2 , H_2S , O_3 , NO_x , total hydrocarbon, total suspended particulates, sulfate and nitrate concentrations have been collected at each of the nine exposure sites under the regional air monitoring system (RAMS). For galvanized steel and weathering steel, four different sets have been exposed in order to study the effect of the atmospheric conditions at first exposure on subsequent corrosion behavior. House paint showed discontinuous corrosion behavior with time. Exposure to the south was more corrosive than exposure to the north for both latex and oil base paint. Tarnishing of silver plated samples was measured by the reflectance loss and by an electrochemical technique. At some sites 50 percent reflectance loss occurred after 3 months exposure. A first attempt has been made to provide statistical correlation between corrosion and atmospheric data using a multiple regression model. Some of the apparent inconsistencies which seem to occur in the estimated effects of pollutants on corrosion behavior are believed to be due to multi-collinearity. Corrosion and pollutant code numbers have been assigned to each test site based on the average corrosion values and pollutant levels. No obvious correlations between corrosion behavior and atmospheric conditions can be obtained by comparison of these numbers.

8. Statistical Assessment of the Effect of Fluctuations in the Atmospheric Concentration of Sulfur Dioxide on the Corrosion Rate of Metals. Y. N. Mikhailovskii and V. A. San'ko. Zashch. Met., v. 15, No. 4, 1979, pp. 432-437 (Russian).*

To obtain functional relations between the corrosion rates of metals and degree of atmospheric contamination by SO_2 , statistical data on SO_2 concentration variation in the rural and urban areas was obtained and analyzed. The corrosion rate of magnesium-alloy MA2-1 was maximum in the winter months. The corrosion rate increased linearly with SO_2 content in the atmosphere up to $35\text{-}40 \text{ mg/m}^3$. At $>100 \text{ mg/m}^3$, the stimulating effect of SO_2 decreased. For Cd, Zn, steel, and Cu the corrosion rate increase per $100 \text{ mg SO}_2/\text{m}^3$ was 2.0, 2.0, 32.0, and $2.6 \text{ mg/m}^2\text{-h}$, respectively. The corrosion rate of metals in the urban atmosphere was 15 to 20 times higher than that in rural atmospheres.

9. The Atmospheric Corrosion Resistance of Stainless Steel. J. E. Truman. Stainless Steel Ind., v. 7, January 1979, pp. 11-13 and 17.

In several programs of work, initiated in 1938, sheet samples of various grades of stainless steel were exposed on a laboratory roof in Sheffield for periods of up to 5 years. Weight loss, extent of surface and maximum pit depth were compared for the different steel grades and surface finishes. A decrease in weight loss with increasing molybdenum content is confirmed. Corrosion rates currently experienced are generally lower than those encountered in earlier tests, due probably to changes in the type and/or quantity of atmospheric pollution.

10. Use of Building Surfaces in the Passive Abatement of Gaseous Air Pollutants. H. S. Judeikis. J. Architectural Research, v. 7, No. 1, March 1979, pp. 28-33.

The potential utilization of building surfaces as a passive means of air pollution abatement is considered here. Representative data from the literature on the removal of gaseous air pollutants (SO_2 , ozone, NO_x) and interaction with common building surfaces (metals and non-metals) are reviewed. Based on these data, sample calculations indicate the magnitude of reduction of indoor pollutant levels anticipated through the use of these materials.

1978

1. Acid Precipitation in the Netherlands. A. J. Vermeulen. Environ. Sci. Tech., v. 12, No. 9, September 1978, pp. 1017-1021.

Around 1966, the highest acid precipitation measurements in the world (on a yearly basis) were made in the Netherlands. Damage to materials is mentioned as one of the environmental consequences of acid rain.

2. ASTM Atmospheric Corrosion Testing: 1906 to 1976. W. H. Ailor. Atmospheric Factors Affecting the Corrosion of Engineering Metals, ASTM STP 646, edited by S. K. Coburn, American Society for Testing and Materials, 1978, pp. 129-151.

In the early fall of 1976 ASTM Committee G-1 on Corrosion of Metals exposed more than 40 ferrous and nonferrous sheet materials at 5 test locations. These exposures are a part of the third 20-year atmospheric test program generated by ASTM corrosion groups since 1932. Metals include new alloys, tempers, and coatings developed since the initiation of the last program.

Exposures have triplicate exposed panels for removal periods of 2, 5, 10, and 20 years at test sites at Kure Beach, North Carolina, 24-m (80-ft) lot; Newark-Kearny, New Jersey; Point Reyes, California; State College, Pennsylvania, and Panama Canal Zone.

Ten metal suppliers are participating in this new long-term test program. Among the metals exposed are Al, Cu, Pb, Mg, Ni, stainless

steel, Ti, and Zn alloys. Aluminized- and galvanized-coated steels are also being tested.

Evaluation of these materials includes weight loss (corrosion rates), pitting depth, and changes in mechanical properties.

One task group is monitoring weather conditions at the sites and another group is calibrating the site corrosivities through periodical short-term (1 and 2 year) exposures of steel and zinc panels during the course of the 20-year tests.

3. Atmospheric Corrosion. M. G. Fontana and N. D. Greene. Chapt. 8 in Corrosion Engineering, McGraw-Hill Company, 2d ed., 1978, pp. 265-268.

A summary of the facts known about atmospheric corrosion is given: the main corrosive agents, the corrosion rates of steel in different atmospheres, the corrosion due to moisture, the high resistance to corrosion of steel alloyed with nickel and copper and especially of stainless steel.

4. Atmospheric Corrosion. T. Hakkarainen. Tutkimus Tek., 1978, No. 4-5, pp. 46-54 (Finnish).*

The main factors affecting the atmospheric corrosion of metals are the wetting time of the metal surface and the SO₂ content of the air. With the exception of carbon steel, metals kept outdoors developed a dense layer of corrosion products which protect the metal surface from further corrosion. The most common protective measure for steel surfaces is to isolate them with a surface coating. Reliable data on corrosion rates can be obtained from long-range field tests during which the climatic conditions are recorded.

5. Atmospheric Corrosion in Marine Environments. R. A. Legault and V. P. Pearson. Corrosion, v. 34, No. 12, December 1978, pp. 433-437.

It has been demonstrated that the natural atmospheric corrosion behavior of low alloy steels in marine environments can be accurately described by an equation of the form: $\Delta W = Kt^N$. With this relationship, reliable predictions of long-term weight losses can be made from as few as two sets of determinations obtained in relatively short exposures. The reliability of this relationship has also been established for galvanized and aluminized steels.

6. Atmospheric Corrosion of Laminar Composites Consisting of Copper on Stainless Steel. A. Baboian, G. Haynes, and P. Sexton. Atmospheric Factors Affecting the Corrosion of Engineering Metals, ASTM STP 646, edited by S. K. Coburn, American Society for Testing and Materials, 1978, pp. 185-203.

Atmospheric corrosion of laminar composites consisting of copper on stainless steels has been studied through direct exposure of copper-clad ferritic and austenitic stainless steels to provide information on

galvanic effects at cut edges and pores in the copper cladding. Qualitative and quantitative results after exposure for 7.5 years are presented and environmental effects are considered. Application of electrochemical techniques for predicting galvanically induced localized corrosion are discussed and related to environmental conditions and alloy composition. Mechanisms for galvanic pitting and crevice corrosion are correlated with service performance of the copper-stainless steel couples.

7. Atmospheric Laboratory Bench. Y. N. Mikhailovskii, V. A. San'ko, N. A. Sokolov, and P. N. Kudryavtsev. *Zashch. Met.*, v. 14, No. 4, 1978, pp. 515-517 (Russian).*

A laboratory bench is described which is used for corrosion tests of metals as applicable to industrial regions. When used in rural regions, SO_2 is added to each cell to imitate the industrial environment. The test chamber (0.7 x 1.4 m) is divided into several cells. Operation of the chamber is automated and it can record the air humidity from 60 to 100 percent and of temperature from 15 to 35°C. Corrosion curves are plotted for Cd, Ni, Cu, Zn, Fe, and Mg under fall and winter conditions in rural regions, with surrounding air containing 2 mg SO_2/m^3 .

8. Corrosion in Old Iron Artifacts. F. K. Naumann. *Werkst. Korros.*, v. 29, No. 5, 1978, pp. 332-334 (German).

Examples are given of the selective action of corrosion in old iron artifacts protected by various natural environments and having varying degrees of carbonization. The structure of the corroded area is examined microscopically to determine possible steps in corrosion. One of the oldest examples of a case of intercrystalline stress cracking corrosion is given.

9. Corrosion Investigations at Panama Canal Zone. M. A. Pelensky, J. J. Jaworski, and A. Gallaccio. *Atmospheric Factors Affecting the Corrosion of Engineering Metals*, ASTM STP 646, edited by S. K. Coburn, American Society for Testing and Materials, 1978, p. 58-73.

This paper reports on the progress of investigations being conducted at the Panama Canal Zone relative to the corrosion of dissimilar metal couples exposed in the atmosphere, in the soil, and in seawater. Machined specimens of Al, brass, Mg, monel, steel, stainless steel, and Ti alloys are included in this study.

Exposure of dissimilar and similar (control) metal couples was initiated over 2 years ago for a planned maximum 5-year exposure. Couple replicates (four of each metal) are removed from exposure periodically and returned to the laboratory for visual examination and weight-loss determinations to evaluate the corrosion effects of each of the environments on the various couples. A total of seven removals from each environmental exposure is planned during the course of the corrosion investigations. To date, five removals of atmospheric specimens, five removals of seawater immersion specimens, and four removals of soil burial

specimens, have been completed over a 2-year period and evaluated by this laboratory. Results of findings to date are presented in this paper.

10. Corrosion of Carbon Steel During Cyclical Exposure to Wet Elemental Sulphur and the Atmosphere. D. D. MacDonald, B. Roberts, and J. B. Hyne. Corrosion Science, v. 18, 1978, pp. 499-501.

The corrosion of carbon steel during cyclical exposure to wet elemental sulphur (four days) and the atmosphere (six days) has been investigated. The integral corrosion rate is found to decrease with successive cycles, thereby demonstrating that oxidation of the sulphide film confers protection to the underlying steel.

11. Deteriorative Effect of Sulfur Pollution on Materials. J. O. Nriagu. Chapt. 1 in Sulfur in the Environment, Part II: Ecological Impacts, edited by J. O. Nriagu, Wiley, New York, N.Y., 1978, pp. 1-59.

The chapter discusses the deteriorative effects of sulfur on cultural artifacts and describes the effects on Fe, steel, Cu, Zn, Al, Mg, building materials, paints, textiles, cement, concrete, paper, and wood.

12. Effects of Air Pollutants on Weathering Steel and Galvanized Steel: A Chamber Study. F. H. Haynie, J. W. Spence, and J. B. Upham. Atmospheric Factors Affecting the Corrosion of Engineering Metals, ASTM STP 646, edited by S. K. Coburn, American Society for Testing and Materials, 1978, pp. 30-47.

A statistically designed laboratory study of the effects of gaseous air pollutants on materials was completed. Weathering steel and galvanized steel were among materials exposed in controlled environment chambers. The direct and synergistic effects of relative humidity, SO_2 , NO_2 , and ozone in a programmed dew/light cycle were studied. For weathering steel, SO_2 , relative humidity, and interaction between the two were the important corrosion rate factors. For galvanized steel, only the direct effects of SO_2 and relative humidity were important. The remainder of the fifteen possible direct and synergistic effects were statistically insignificant.

13. Extent of the Destructive Effect of Sulfur Dioxide on Some Chromium Steel Grades Under Different Humidity in Air. Translated by B. Cwynar. Translation, BISI 17219, December 1978, 17 pp.

This article includes the results of field investigations that were realized at two experimental stations situated within the acting range of a point source emission of SO_2 and differing in the emission value of this gas. The investigations intended to determine the influence of the air humidity on the intensity of the corrosive effect of atmospheres containing various amounts of SO_2 .

14. Laboratory Testing of the Atmospheric Corrosion of Steel. T. Sydberger and R. Ericsson. *Werkst. Korros.*, v. 28, No. 3, 1977, pp. 154-158.

Laboratory exposure tests on mild steel were run with controlled pH, temperature, SO₂ concentration, and air flow rate. The metal surface is affected by atmospheric factors such as wind direction and velocity, and location and orientation of the metal surface. With increasing SO₂ concentration, the mild steel corrosion mechanism changes, giving corrosion products with protective properties different from those formed under normal atmospheric conditions. Wetting of steel surfaces due to rain, fog, or dew plays an important role in the atmospheric corrosion of steel.

15. Surface Characterization of Atmospherically Corroded and Blast Cleaned Steel. C. Calabrese and J. R. Allen. *Corrosion*, v. 34, No. 10, 1978, pp. 331-338.

The surface of carbon steel samples was corroded in an industrial atmosphere, abrasive blasted, environmentally corrosion tested, and examined by optical and electron microscopy. When corrosion tested at 25° C and 50 to 100 percent relative humidity, the industrially corroded and sandblasted steel quickly formed new corrosion product. For the same exposures, the new mill or corroded/ground/blasted steels showed no new corrosion. Atmospheric corrosion of steel proceeded heterogeneously, with the corrosion products containing atmospheric chlorine and sulfur. When sandblasted, the steel surface was layered by plastic deformation of the pit walls trapping the scale product in surface folds. In the presence of moisture, the trapped corrosion sites became active nuclei for the rapidly formed new corrosion. In contrast, the normal passive oxide on uncontaminated steel retarded new corrosion. Sites contaminated with sulfur or chlorine were responsible for initiating new corrosion, and were the likely sites for ultimate paint and coating failures.

16. The Changing Chemistry of Precipitation and Its Effects on Vegetation and Materials. E. B. Cowling and L. S. Boehinger. *Control and Dispersion of Air Pollutants, Emphasis on NO_x and Particulate Emissions*, edited by R. L. Byers, D. W. Cooper and W. Licht. American Institute of Chemical Engineers Symp., Series No. 175, v. 74, 1978, pp. 134-142.

The results of European precipitation measuring network studies are reported. The growth and development of plants, the reproductive capacity of fish and the stability of exposed masonry, stone, and metal structures are discussed as they are affected by sulfuric and nitric acid.

17. The Corrosion and Protection of Metals in the Building and Construction Industries. B. G. Callaghan. *J. Oil Color Chemists Assoc.*, v. 61, No. 11, November 1978, pp. 411-418.

A short review of the mechanism of corrosion by bimetallic action and by factors in the environment, estimates of the rate of corrosion of different metals in areas of South Africa, and a summary of the use of

different metals in building and the methods used to protect them is given. Effects on steel, low-alloy steels, copper and copper alloys, aluminum and its alloys, stainless steel, lead and zinc, are included.

18. The Corrosion Prevention History of the Eiffel Tower. H. Rabate. *Applica*, v. 85, No. 17, 1978, pp. 12-13.

The important data of anti-corrosive measures between 1892 and 1969 are outlined, including the type of primers and topcoat, whenever available. Red lead, iron oxide, lead silicochromate, linseed oil and alkyd resin were featured in the formulations last used.

19. The Influence of SO_2 on the Corrosion of Steel. N. G. Vanneberg. *Extended Abstracts*, 154th ECS Meeting, Pittsburgh, Pa., v. 78, No. 2, October 1978, p. 314.

Metal samples were exposed to a test atmosphere with SO_2 concentration (SDC) between 0.01 to 100 ppm and a relative humidity (RH) between 20 to 100 percent at controlled concentrations of other gases, gas flow and temperature. At RH above 80 percent and SDC of 0.1 ppm, every SO_2 molecule which strikes a steel surface is absorbed and converted to sulfuric acid or sulfates. The further corrosion is determined not only by the sulfur content in the atmosphere but also by the supply of SO_2 . At high concentrations of SO_2 (above 10 ppm) SO_2 acts as an inhibitor.

20. The Influence of Sodium Chloride on the Atmospheric Corrosion of Steel. R. Ericsson. *Werkst. Korros.*, v. 29, No. 6, 1978, p. 400.*

Mild steel specimens covered with NaCl crystals ($8\mu\text{gNaCl}/\text{cm}^2$) were exposed to an SO_2 -free atmosphere at different relative humidities. The combined effect of NaCl crystals on a steel surface and SO_2 in the atmosphere were investigated. On exposure of specimens with NaCl in an SO_2 -free atmosphere the extent of corrosion increased with increasing relative humidity from 58 to 90 percent, interrupted by a sharp min. at about 87 percent relative humidity. Scanning electron microscopy studies showed that tower shaped corrosion products were formed at a high relative humidity while filiform corrosion appeared when the relative humidity was lowered. At 90 percent relative humidity more corrosion was observed with clean steel specimens and an SO_2 supply of $1\mu\text{g}/\text{cm}^2\text{-h}$ than with NaCl crystals on the surfaces ($8\mu\text{g NaCl}/\text{cm}^2$) in the absence of SO_2 . In the combined influence of NaCl on the steel surfaces and SO_2 in the atmosphere, a synergistic effect was noticed at 90 percent relative humidity. At 70 percent relative humidity no influence of an SO_2 supply of $1\mu\text{g SO}_2/\text{cm}^2\text{-h}$ on the corrosion of steel specimens with NaCl crystals on their surfaces could be observed.

21. The Results of a Thirty-Month Exposure Study of Steels and Other Materials to Airborne Sulfur Pollutants in St. Louis, Missouri. F. Mansfeld. *Corrosion/78*, National Association of Corrosion Engineers, Houston, Texas, Paper No. 88, 1978, 16 pp.

Samples of galvanized steel, weathering steel, silver, house paints, marble, and stressed aluminum alloy were exposed at nine sites in St. Louis, Missouri, for up to 30 months, starting in October 1974, in a study done by Rockwell International Corporation for the Environmental Protection Agency (EPA). Atmospheric data were also collected at the same sites. Samples were evaluated by various techniques, for example, weight loss and time-to-failure measurements. Significant differences in corrosion behavior and atmospheric conditions were observed for the different test sites. The corrosion data are presented and discussed in detail. In the final report to EPA, the corrosion data will be correlated with air quality parameters such as temperature, relative humidity, SO_2 , H_2S , particulate sulfate and nitrate, O_3 , nitrogen oxides, and total hydrocarbon in order to determine the effects of these parameters on atmospheric corrosion rates.

22. The Structure of Iron-Carboxylic Acid Surface Films. J. C. Wood. Corrosion, v. 34, No. 2, 1978, pp. 70-72.

Protective films containing a COOH group were formed on iron, and their merits as corrosion inhibitors compared. Films of benzoic acid and m-nitrobenzoic acid gave the best protection against SO_2 , while oxalate films gave some protection. A stearic acid film did not protect against corrosion by SO_2 . The bond type between film and metal was studied with X-ray photo-electron spectroscopy.

1977

1. Aims and Results of the Effect Inventory of North Rhine Westphalia. G. Scholl, B. Prinz and D. Schwela. Proc. 4th. Intern. Union Air Pollut. Prev. Assoc., Intern. Clean Air Congr. (Tokyo, Japan, May 16-20, 1977), 1977, pp. 48-51.

Starting in 1972, the effects of air pollution were surveyed in North Rhine Westphalia. Standardized acceptors were exposed on sites which were distributed systematically, in analogy to a related air pollution survey. The survey included monitoring of the effects of integrated air pollution exposure on lichen thalli (hypogymnia physodes) and steel plates, as well as monitoring of the lead burden of newborn babies and their mothers. The survey showed that the effects of phytotoxic air pollution are significantly higher in the Ruhr area than in the boundary zones (especially the Rhine area outside Duisburg). At least 64% of the spatial variation in lichen mortality can be attributed to air pollution. Corrosion rate measurements on steel plates showed that in the area which extended along the Rhine River from south of Cologne to north of Leverkusen, the maximum corrosion rate of 2.97 g/sq.m/day was only half the maximum rate found in the "Ruhr Area West" of 5.43 g/sq.m/day.

2. Application Properties. The Effect of Climatic and Pollutant Factors on the Atmospheric Corrosion of Steel. Laboratory Predetermination. J.

Van Muylder and M. Pourbaix. Comm. Eur. Communities (Rep.) EUR 5840, 1977, 53 pp. (French).*

The corrosion of steels Fe 37, Fe 52, a weathering steel, and a corrosion-resistant marine steel depended on the chloride and sulfur dioxide contents of the rain water as well as on the metal temperature during drying. The best protective oxide coatings were obtained by corroding in 10^{-2} M NaHSO_3 nonpolluted-rain, rinsing, and drying at approximately 60°C .

3. Corrosion Due to the Action of Industrial Emissions on Steel Structures in the Industrial Region of Ostrava, Czechoslovakia. M. Kulis. Werkst. Korros., v. 28, No. 2, February 1977, pp. 89-97 (German).

Corrosion was assessed for a number of representative structures, namely: (1) high-voltage lines; (2) steel railway bridges and underpasses; (3) gasholders; (4) winding towers; and (5) contact lines and masts. Regular renewal, steel coating, efficient processes for corrosion prevention, and control of industrial emissions are required.

4. Corrosion Environment Factors on Automobile Bodies. A. M. Kalson, Jr. SAE No. 770291, Society of Automotive Engineers, 1977, 4 pp.

The service life of an automobile body is dependent upon several atmospheric environmental factors. Through surveys and data interpretation, a comparison of these factors in various areas of the country is shown. Through the comparison of the survey data from each area, it was determined that automobile body corrosion is caused by the presence of such agents as road dust and dirt, salts, gases such as SO_2 , and the presence of moisture in the form of rain, snow, fog, dew, or high humidity. Corrosion rates in each region, as measured by perforated body panels, were dependent upon the amount of the foreign agents present and the degree and duration of moisture. Also, corrosion rates under dynamic conditions may greatly differ under static conditions in the same environment or electrolyte.

5. Effects of Sulphur Dioxide on Materials. S. K. Gajendragadkar. Chem. Age India, v. 28, No. 8, 1977, pp. 673-677.

A discussion covers meteorological factors (humidity, temperature, sunlight, wind) which influence the effect of atmospheric sulfur dioxide on materials; the effect of sulfur dioxide on various materials, including the corrosion of metals, chemical action on marble, limestone, and other building materials, embrittlement and weakness of paper and leather, and weakening and disintegration of textiles; corrosion acceleration by particulate matter which absorbs sulfur dioxide from the atmosphere; and the principal pollutant and other factors causing damage to metals, building materials, paints, leather, paper, textiles, dyes, and rubber.

6. Effects on Economic Materials and Structures. J. E. Yocom and J. B. Upham. Chapt. 2 in Air Pollution, edited by A. C. Stern, Academic Press, New York, N.Y., v. 2, 1977, pp. 65-116.

Mechanisms of deterioration in polluted atmospheres are discussed, including factors that influence atmosphere deterioration. Methods of measuring atmospheric deterioration are given. Damage to metals, building materials, protective coatings, leather, paper, textiles, textile dyes, elastomers, glass and ceramics, works of art, electronic components is discussed along with the economics of air pollution effects.

7. Evaluation of the Atmospheric Corrosion Behavior of Structural Steels. J. L. Pagniez and J. C. Charbonnier. Rev. Metall., v. 74, No. 6, June 1977, pp. 359-365 (French).

Testing methods and experimental results for bare and coated low carbon steels are described. A technique consisting of field exposure of samples of thin sheet for short times (3 months) was found sufficient to judge the comparative aggressivity of different locations or, at a given location, the aggressivity of different seasons. Some comparisons are made with accelerated laboratory tests.

8. Evaluation of the Behavior of Structural Steels Exposed to the Atmosphere--Test Methods and Examples of Experimental Results Concerning Uncoated Steel or Steel Unprotected by Paint. J. L. Pagniez and J. C. Charbonnier. Mater. Tech., v. 65, No. 5, May 1977, pp. 253-258 (French).

Test results are presented which make it possible to evaluate the behavior of certain common structural steels exposed for several years to the atmosphere at three stations in France--namely, Saint-Germain-en-Laye (semirural atmosphere), Saint-Denis (industrial atmosphere), and Biarritz (maritime atmosphere). An analysis is then made of results obtained with the aid of accelerated laboratory tests designed to simulate the behavior of iron and steel products in different types of atmosphere with the aid of a salt mist and with the aid of immersion-emersion test. Finally, the results of short-term tests of thin mild steel sheets are presented with a view to comparing the aggressivity of different sites or the aggressivity of a single site at different times.

9. Galvanic Corrosion In the Atmosphere. V. Kucera. Rapp.-Korrosionsinst., No. 16, 1977, 43 pp. (Swedish).*

The galvanic atmospheric corrosion of 86 selected combinations of carbon steel, stainless steel Cu, Pb, Zn, Ni, Al, anodized Al, Sn, Cr, Mg, and weathering steel was investigated at test sites in rural, urban, and marine atmospheres using the wire-on-bolt method. The influence of exposure in a rain-sheltered position and the influence of the distance from the sea and the position along the Swedish coast were studied with a restricted number of material combinations.

10. Investigation into Atmospheric Corrosion With an Electrochemical Cell. W. Friehe and W. Schwenk. Stahl Eisen, v. 97, July 1977, pp. 685-686 (German).

An investigation into the possibility of using a corrosion cell consisting of alternate plates of steel and copper separated by plastic insulators for the assessment of the likely corrosion behavior of constructional steels in service showed that such short-term tests were not indicative of the corrosion behavior of the steels over long times. The readings from the cell were markedly affected by the weather conditions and over a fairly long period would provide an overall assessment of weather factors at a particular site.

11. Physicomathematical Modeling of Steel Corrosion Under Atmospheric Conditions. Y. N. Mikhailovskii, V. V. Agafonov, and V. A. San'ko. Zashch. Met., v. 13, No. 5, 1977, pp. 515-522 (Russian).*

The continuous measurement of the corrosion rate of steel St. 3 wire for 3 years by a resistivity method, the time of water-phase film retention on the metal, concentration of SO_2 , and of total solar radiation were used in modeling atmospheric steel corrosion in agricultural regions. The parameters of the model were determined by regressive analysis of corrosion and meteorological statistical data. Coefficients were obtained encompassing the effect of temperature and minor SO_2 concentrations on the corrosion rate of steels. The strong effect of solar exposure on the rate of photochemical reaction of SO_2 oxidation to SO_3 and the activation of corrosion was observed. The model allows calculation from the known meteorological data of the expected corrosion rate with ± 12 percent accuracy and 0.95 probability.

12. Short-Term Atmospheric Corrosion of Mild Steel at Two Weather and Pollution Monitored Sites. J. B. Johnson, P. Elliot, M. A. Winterbottom, and G. C. Wood. Corrosion Science, v. 17, 1977, pp. 691-700.

Results are recorded of topographical details, weight loss, and corrosion product analysis for short-term atmospheric exposure of mild steel, in relation to weather and pollutant factors. Various structured corrosion features, for example, doughnut-like, were noted. The major corrosion product found by $\gamma\text{-Fe}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$, with some $\gamma\text{-Fe}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$ and $\alpha\text{-FeOOH}$. Wet initial conditions of exposure and subsequent high levels of humidity were found to have the dominant overriding effect in promoting corrosion losses. Smoke was shown to be capable of exerting a very strong influence upon the effective corrosivity of atmospheric sulfur dioxide.

13. Study of Atmospheric Corrosion Inhibitors on Metal Surfaces by X-Ray Electron Spectroscopy. A. N. Novitskii, Y. V. Salyn, and V. I. Nefedov. Zashch. Met., v. 13, No. 2, 1977, pp. 209-212 (Russian).

The corrosion of aluminum alloy D-16, copper, and steel and the action of corrosion inhibitors were studied by X-ray electron spectroscopy. Four inhibitors were tested: Akor-1 (p-alkyl

nitrobenzene), BMP ($R\text{-Ph-SO}_2\text{NHCO}_2\text{NH}_2$), G-2 (Hexamethylenimine m-nitrobenzoate), and Cr-Gu (guanidine chromate). The inhibitors were adsorbed on oxide films formed on the metal surfaces. BMP, G-2, and Cr-Gu were tightly bound to the surface, preventing their evaporation at 10^{-6} torr.

1976

1. Acid Precipitation. G. E. Likens. Chemical and Engineering News, v. 54, No. 48, November 22, 1976, pp. 29-44.

The acidity of rain and snow falling on parts of the United States and Europe has been rising for reasons that are still not entirely clear and with consequences that have yet to be evaluated. Acidity of precipitation has increased markedly in the eastern United States and in Scandinavia during the past two decades.

2. Application of Thin-Layer Electrochemistry to the Study of Atmospheric Corrosion. C. Fiaud and F. Tirbonod. Met.: Corros.-Ind., v. 51, 1976, pp. 388-393 (French).*

The method of thin-layer electrochemistry has the advantage of defining well the electrochemical system under study. The variation of polarization resistance as a function of the thickness of the thin layer on Armco iron in 1M Na_2SO_4 solution was studied. The polarization resistance is of the same order of magnitude in the case of atmospherically condensed water acting as the thin layer. The method was also applied to the study of a well-known volatile inhibitor, cyclohexylamine carbonate (CCA), for iron and steel. The CCA is predominantly an anodic inhibitor. The effect was studied of $(\text{NH}_4)_2\text{CrO}_4$ on the atmospheric corrosion of the aluminum alloy Au4G1. The classical electrochemical methods used for the study of corrosion in solutions (current-potential curves as polarization resistance) likewise give, in this case, useful indications concerning both the degree of protection of the metal surface and knowledge concerning the fundamental processes of atmospheric corrosion.

3. Atmospheric Attack (Steel Dowels) and Measures Taken. T. Skoulikidos. Proc. 2nd Int. Symp. Deterior. Building Stones, 1976, pp. 347-349 (French).

The atmospheric corrosion of steel dowels in marble and concrete structures in Athens due to the subsequent cracking of adjacent concrete is discussed. Measures for eliminating corrosion are discussed, and it is concluded that titanium steel alloy dowels containing 4 percent Mn and 40 percent aluminum should be used to replace the corroded dowels.

4. Effect of Climate on the Formation and Structure of the Protective Layers on Corrosion-Resistant Steels. H. Baum and K. Roessler. Freiberg. Forschungsh. B., v. B189, 1976, pp. 81-95 (German).

Properties of rust layers were determined for corrosion-resistant steels depending on the aggressiveness of the atmosphere, the exposure time, and composition of the steel. The structure and thickness of the rust layer were examined metallographically. X-ray analyses were made for element distribution. Rust growth with moisture absorption and desorption and sulfate spot distribution were also examined.

5. Effects of Gaseous Pollutants on Materials: A Chamber Study. F. H. Haynie, J. W. Spence, and J. B. Upham. NTIS Report PB-251580, 1976, 98 pp.

This document describes a comprehensive laboratory study using specially designed controlled environment exposure chambers to assess the effects of gaseous air pollutants (SO_2 , NO_2 , and ozone) on a variety of materials. Materials included weathering steel, galvanized steel, aluminum alloys, paints, drapery fabrics, white sidewall tire rubber, vinyl house siding, and marble. The exposure experiment was statistically designed using a two-level factorial arrangement to identify the environmental factors or combination of factors, or both, that cause materials damage. Over 200 different direct and synergistic effects were examined. The study revealed that only 22 of the possible effects were statistically significant at better than a 95 percent confidence level. Sulfur dioxide, relative humidity and the interaction between them were the main factors causing effects. A number of empirical functions were developed that relate materials effects to various factors causing the effects. An exceptionally good relationship was obtained for the corrosion of weathering steel. The lack of statistical significance that was found for the large majority of effects that were studied is equally as important for the significant effects. As a result a large number of material-pollutant combinations may be excluded from further detailed study.

6. Effects of Power Plant Emissions on Materials. J. E. Yocom and N. Grappone. Research Corporation of New England, Wethersfield, Connecticut, NTIS Report PB-257539, July 1976, 85 pp.

This study assesses the available knowledge on the effects of air pollutants on materials with special emphasis on those pollutants emitted from or related to emissions from fossil fuel power plants. The study indicates the relative importance of these various effects, summarizes current research on the material effects of air pollution, and identifies areas of needed research. The areas of suggested future research include the effects of atmospheric sulfates on materials, the effects of air pollutants on concrete, evaluation of the effects of acid smut from oil-fired boilers, and the development of more accurate estimates of SO_2 damage costs to materials.

7. Effects of Sulfur Dioxide and Acid Precipitation on Metals and Anti-Rust Painted Steel. V. Kucera. *Ambio.*, v. 5, No. 5-6, 1976, pp. 243-248.

Data on the corrosion rates of unprotected C-steel, Zn and galvanized steel, Ni and Ni-plated steel, Cu, Al, and anti-rust painted steel due to SO_2 and acid precipitation in Sweden are reported. Corrosion rates are significantly higher in polluted urban atmospheres than in rural atmospheres because of the high concentrations of airborne sulfur pollutants in urbanized areas. Economic damage is significant in the case of galvanized, nickel-plated, and painted steel, and painted wood. Damage in the United States in 1970 is estimated at about \$7.10/yr/person while the corresponding Swedish figure is \$4.30/yr/person.

8. Electrical Conductivity Changes in α -FeOOH and β -FeOOH Upon Surface Dehydration. K. Kaneko and K. Inouye. *Bull. Chem. Soc., Japan*, v. 49, No. 12, 1976, pp. 3689-3690.

The electrical conductivity of α -FeOOH and β -FeOOH, preheated at 100 to 140°C in vacuo, was determined over the temperature range from 0 to 140°C. The conductivity increased considerably with a rise in the preheating temperature. The increase appears to be due to Fe^{2+} ions produced by surface dehydration in the preheating.

9. Electrochemical Monitoring of Atmospheric Corrosion Phenomena. F. Mansfeld and J. V. Kenkel. *Corrosion Science*, v. 16, No. 3, 1976, pp. 111-122.

An atmospheric corrosion monitor (ACM) which consists of copper/zinc or copper/steel couples, has been used to study various aspects of atmospheric corrosion. Calibration of ACMs is carried out under 1 ml of distilled water. A detailed study was related to the effect of salt particles on atmospheric corrosion. While no current flow and no corrosion occurred on clean surfaces, large increases of the galvanic current were observed when salt particles were placed on the ACM surface provided that the relative humidity (RH) in the test cell was higher than the RH value of a saturated solution of the salt particle applied. The ACM has also been used to monitor changes in the composition of gaseous atmospheres (air, N_2 , N_2 plus SO_2). Outdoor exposure of the copper/zinc and copper/steel ACM suggests that this instrument can be used not only to monitor time-of-wetness, but also the corrosivity of a test environment.

10. Electrolytes for Studying the Electrode Processes on Thin Films During Atmospheric Corrosion Tests. G. K. Dzhincharadze, V. S. Kemkhadze, S. N. Mandzhgaladze, and E. V. Glonti. *Zashch. Met.*, v. 12, No. 1, 1976, pp. 113-115 (Russian).*

The electrode potentials and polarizabilities of St 3 steel were studied under thin films of rainwater and dew representing inland conditions and of seawater and 0.1N NaCl representing coastal conditions.

11. Investigation Into Sulfur Dioxide Corrosion of Iron. A. J. Sprott.
Prepr. Pap., Annu. Conf. Australas. Corros. Assoc., Paper No. 29, 1976,
9 pp.*

The mechanism was studied of atmospheric corrosion of iron in industrial atmospheres containing SO_2 from the combustion of sulfur-containing oil. After weathering for some time the rust components are α - and γ - FeOOH which are separated from the substrate by an Fe_3O_4 layer. A clean iron surface generally contains approximately $0.1 \mu\text{g H}_2\text{O}/\text{cm}^2$ at a relative humidity of 22 to 97 percent. As the rust film increases, an anodic reaction occurs at the substrate surface and a cathodic reduction at the $\text{Fe}_3\text{O}_4/\text{FeOOH}$ interface followed by atmospheric oxidation. The electrons flow through the magnetite layer and the Fe^{2+} ionic flow occurs via H_2O molecules which are retained in the magnetite voids. Sulfur dioxide becomes involved in the corrosion after oxidation to SO_4^{-2} which accelerates the corrosion rate because of an increase in Fe^{2+} transfer at the iron surface to the FeOOH layer. The only sulfur-containing compound is $\text{FeSO}_4 \cdot 4\text{H}_2\text{O}$ in long-term corrosion. The SO_2 uptake by the surface is irreversible and it becomes chemisorbed until its oxidation to SO_4^{-2} . For the 0.5- to 4-hr test, SO_2 gas was labeled with sulfur. The SO_2 uptake by absorption increased from 1×10^5 to 38×10^5 m/s with increasing relative humidity from 65 to 100 percent.

12. Methods for Determination of Corrosion Losses. M. Kulis. Ochr. Koroz., v. 19, No. 9, 1976, pp. 235-237 (Polish).

In a review with two references, the atmospheric corrosion of alloys (for example, steels), its prevention, and determination of corrosion losses are discussed.

13. Physical and Economic Damage Functions for Air Pollutants by Receptor. B. Liu and E. S. Yu. Report No. EPA-600/5-76-011, U.S. Environmental Protection Agency, September 1976, 172 pp.

This study is primarily concerned with evaluating regional economic damages to human health, material, and vegetation, and of soiling resulting from air pollution. This study represents a step forward in methodological development of air pollution damage estimation. It attempts to construct essential frameworks of the physical and economic damage functions which can be used for calculating comparable regional damage estimates for the several important receptors--human health, material, and household soiling--regardless that these damage estimates may appear to be tentative. More importantly, aggregate economic damage functions instrumental for transforming the multifarious aspects of the pollution problem into a single, homogeneous monetary unit are tentatively derived and illustrated. It is hoped that these results will be of some use to guide policymakers as they make decisions on the implementation of programs to achieve "optimal" pollution levels for this country. Given the experimental nature of the methodological and statistical procedures and the degree of uncertainty associated with the study results, a great deal of caution should be exercised in using the products of this research.

14. Protection Against Atmospheric Corrosion. K. Barton. Translated by J. R. Duncan, Wiley, New York, N.Y., 1976, 194 pp.

This book discusses the atmosphere as a corrosive environment, mechanisms and kinetics of atmospheric corrosion, non-uniform and structural corrosion phenomena, principles of protection against atmospheric corrosion, and technical and scientific considerations in atmospheric corrosion protection.

15. Steel from Ferrous Can Scrap. S. D. Cramer and H. V. Makar. 5th Mineral Waste Utilization Symp., U.S. Bureau of Mines and IIT Research Institute, April 13-14, 1976, pp. 398-406.

This paper describes a Federal Bureau of Mines' study on the evaluation of ferrous can scrap as melting stock for steelmaking. Ferrous can scrap, pretreated in various ways, was melted and cast into 50-pound and 800-pound ingots. Melt compositions corresponded to carbon steel and high-strength low-alloy steel products. Rebar and steel plate were rolled from these ingots. Mechanical properties of the resulting products, including tensile properties, impact strength, and hardness, were determined. A comprehensive corrosion study is also being conducted on the products. Atmospheric weathering data for panels exposed up to 1.5 years at marine, rural, and industrial sites are reported. The compositions of the corrosion films were determined. Laboratory corrosion studies, including CASS-spray tests, were also conducted on the steel products made from ferrous can scrap.

The tensile properties and hardness of the can scrap products were comparable to those of similar commercial products. Under laboratory conditions, no difficulties were encountered in hot rolling the can scrap products. The impact strength of the can scrap carbon steels was not adversely affected by the residual elements. The atmospheric corrosion resistance of carbon steels made from incinerated and nonincinerated-nondetinned can scrap was equivalent to or better than that of a similar commercial product in marine, rural, and industrial environments. Residual tin enhanced the corrosion resistance of the scrap carbon steels. The atmospheric corrosion resistance of can scrap COR-TEN B was unaffected by the residual elements.

16. Structural Analysis of Monuments. S. Angelides. Chapter in The Acropolis-Hellenic Republic, Ministry of Culture and Science, Athens, Greece, 1976, pp. 19-22.

During Balanos' restoration of the Acropolis in 1903, steel reinforcements were added both inside and between the marble pieces thus changing the structural foundation of the monument. The internal and external cracks in the stone and the discontinuity in the joints are due in part to the oxidation and inevitable expansion of the steel reinforcements. Gamma-ray examination has identified the location of the steel in the marble, the degree of its oxidation, and the location of internal cracks in the marble. A steel beam was placed in the Erechtheion of the Acropolis in order to take the weight off the Caryatid statues. It was found that this beam, placed in 1903, is not serving its intended

purpose and must be removed. The southern and western walls of the Erechtheion are unsafe. All parts of the Erechtheion, except the foundation, need structural reinforcement.

17. The Corrosion of Steel and the Dangerous Chlorides. A. Bresle. Met. Finish., v. 74, No. 8, 1976, pp. 23-25 and 30.

The role of chloride in the atmospheric corrosion of steel has been underestimated; sulfur compounds are considered as the leading rust accelerators. Recent evidence indicates that chloride is present in the immediate boundary layer between rust and steel, in an appreciable concentration. Chloride was found to induce corrosion in a concentration as low as 10 mg Cl/m² steel surface, even on steel surfaces which have been cleaned by conventional pickling. Ordinary sand blasting techniques are not considered to clean rusty steel surfaces sufficiently in the preliminary step in protective coating.

18. The Effect of Copper (II) on the Formation of γ -FeOOH. K. Inouye, K. Ichimuro, K. Kaneko, and T. Ishikawa. Corrosion Science, v. 16, 1976, pp. 507-517.

Various γ -FeOOH samples have been synthesized by air oxidation of FeSO₄ solution with or without addition of Cu(II) (0-46 at. pct. Cu/Fe) and examined by X-ray diffraction, electron-microscopic observation, BET surface area determination, infra red absorption, DTA and chemical analyses. A destructive action of doped Cu(II) ions on the crystal formation was apparently recognized and discussed based on the crystallographic structure. The possible mechanism of crystallization of γ -FeOOH appears to differ between pure and Cu-doped γ -FeOOH, particularly one containing nearly 50 percent Cu.

19. Use of the Method of Polarization Resistance for Studying the Atmospheric Corrosion of Metals. V. A. Kuznetsov, S. G. Polyakov, Y. S. Gerasimenko, and Y. G. Kotlov. Zashch. Met., v. 12, No. 6, 1976, pp. 667-670 (Russian).

Corrosion determined by the title method showed good agreement with the composition of the corrosion products, as found by atomic absorption spectroscopy. Tests were conducted with copper and steel, first immersed in an aqueous solution of 0.062-percent MgSO₄·7H₂O plus 0.0124-percent CaCl₂ at 20°C and then transferred to a 100-percent relative humidity chamber, with subsequent introduction of ammonia. The polarization resistance was found by deducting the ohmic resistance of the electrolyte film from the combined polarization and ohmic resistances obtained by usual methods.

1975

1. Atmospheric Corrosion of Carbon Steel in Tokyo. T. Komeiji, T. Oodaira, and M. Kadoi. Taiki Osen Kenkyu, v. 9, No. 5, 1975, pp. 677-683 (Japanese).*

The corrosion rates were detd. of JIS G314 steel at 53 sites in Tokyo. Corrosion was severe in industrial and com. areas, medium in the surrounding areas, and slight in western suburbs of Tokyo. The degree of corrosion rates almost coincided with the SO_2 distribution. Correlation anal. of corrosion rates showed that it was mainly affected by temp. and SO_3 and chloride contents of the atm. The effects of environmental factors on corrosion rates are given by a multiple regression equation.

2. Atmospheric Corrosion of Stainless Steels. A. Karlsson and J. Olsson. 7th Scand. Corrosion Congress, 1975, pp. 71-86.**

Sheets of Cr, Cr-Mn-Ni, and Cr-Ni, Cr-Ni-Mo stainless steels were exposed for ten years at five different sites representing marine, city, inland rural, heavily polluted industrial, and less severely polluted industrial atmospheres. The effects of the different surface conditions of the steels, e.g., cold-rolled, hot-rolled, ground, or polished, were also studied. The rural inland atmosphere had little effect, even on a 13% Cr steel, but the marine atmosphere caused pitting in an 18:8 Cr-Ni steel and discoloration of the high-alloy steel 2343. The surface condition is very important in marine environments but has little effect in industrial atmospheres.

3. Bimetallic Corrosion Effects on Mild Steel in Natural Environments. K. E. Johnson and J. S. Abbott. NTIS Report PB-243665, 1975, 17 pp.

Corrosion rates of mild steel, when coupled to each of 31 other metals and alloys, have been determined in 5 natural environments using disk-type specimens. These environments were industrial, urban/rural and marine atmospheres, natural water, and sea water. The relative order of the effect on the corrosion rate of mild steel in each environment is tabulated. The performance of mild steel in a given couple can differ appreciably in different environments.

4. Corrosion Behavior of Low-Alloyed Steel. D. Knotkova-Cermakova, A. Kupilikova, J. Honzak, and J. Vlckova. Korrosion (Dresden), v. 6, No. 2, 1975, pp. 8-22 (German).**

The production and use of steels equivalent to Corten increased in Czechoslovakia. Under the designation Steel 15,217, five series of corrosion tests were made on steels without protective coatings in a variety of atmospheres, including some corrosive industrial locations. In every case the low-alloy steels were superior to plain-carbon steels. Modification of the base composition gave similar results. At a chemical factory the corrosion rate was relatively high. Some exposure tests were also made with protective coatings of synthetic and polymer systems.

These resulted in improved protection of low-alloy steels over plain carbon steels similarly coated. In accelerated laboratory tests in atmospheres with and without added SO_2 , using coated test pieces, the superiority of the low-alloy steel and the advantage of coating were confirmed.

5. Corrosion of Coated Metals. 6. Atmospheric Exposure. J. B. Mohler. Met. Finish., v. 73, No. 9, 1975, pp. 48-51.

The atmospheric corrosion of steel and zinc-coated steel in various urban, industrial, marine, and rural areas is described. Recommendations for outdoor test procedures for obtaining accurate and comparable results are given.

6. Corrosion of Low-Alloy Steels in Polluted Atmospheres. D. Knotkova-Cermakova, and V. Marek. Koroze Ochr. Mater., v. 19, No. 3, 1975, pp. 45-48 (Czech).**

The rate of corrosion of bare, low alloy steel panels exposed to the elements on open racks tends to stabilize over 3 years provided the SO_2 contamination from the atmosphere does not exceed a critical value C , where C equals $80-90 \text{ mg/m}^2 \text{ day}$. Six years of exposure of Atmofix 52A in atmospheres of second- and third-degree aggressivity established that the surface builds up a protective coating of rust. Within a shuttered enclosure in the same atmosphere, but without the benefit of periodic rinsing away of soluble corrosion products and periodic drying in the sun, this equilibrium is not reached. The weight loss in the enclosures was at least twice as that on the open-weather rack at the same station. The stabilized rates during the 3- to 5-year period were low and in atmospheres of low pollution were practically zero. The presence of chlorides significantly increased corrosion.

7. Corrosion Resistance of Stainless Steels in the Atmosphere. Evaluation of the Results of Weathering Tests Up to 10 Year's Duration. R. Ergang and M. B. Rockel. Werkst. Korros., v. 26, No. 1, 1975, pp. 36-41 (German).

Weathering tests on different stainless steels for 10 years gave results similar to exposure for 1 year. An 18-10-2 Cr-Ni-Mo steel can be used even under the most severe conditions. A steel containing 17 percent chromium was considerably attacked in industrial and marine atmospheres and is not suitable for the external parts of buildings. An 18-8 chromium-nickel steel was completely resistant to urban atmospheres. In all cases, the corrosion resistance of the steels was increased by electropolishing. The susceptibility to pitting corrosion decreased with increasing resistance to atmospheric corrosion.

8. Dielectric Behavior of Water Molecules Adsorbed on Iron (III) Oxide Hydroxides. K. Kaneko, M. Serizawa, T. Ishikawa, and K. Inouye. Bull. Chem. Soc., Japan, v. 48, No. 6, 1975, pp. 1764-1769.

The change in the dielectric constant of α -FeOOH, β -FeOOH, and γ -FeOOH with the amount of adsorbed water was examined at 30.0°C in the frequency range 200 Hz--100 kHz for the purpose of clarifying the mechanism of water adsorption. The adsorption isotherms belong to the BET II type. The sample with the adsorbed water shows a particular dispersion of the dielectric constant with frequency in the low frequency range. The dispersion was ascribed to the transition between different orientational directions of the dipole moment of the adsorbed water. The change in the dielectric constant with the amount of adsorbed water for each iron (III) oxide hydroxide was interpreted in relation to the surface structure of predominant faces of crystals, in particular the number and position of hydroxyls on crystal surfaces. The following adsorption process was suggested below the monolayer adsorption coverage for each iron (III) oxide hydroxide. For α -FeOOH, water molecules are adsorbed on the (100) planes in three successive steps. For β -FeOOH, water molecules are primarily bound in the tunnels existing in the crystal along a direction parallel to the c-axis and then are adsorbed on the cracked tunnels exposing to the outer surface. For γ -FeOOH, water molecules are adsorbed on the (010) planes in two steps.

9. Efficient Protection of Steel Structures from Atmospheric Corrosion. D. Knotkova-Cermakova, F. Hasil, and K. Barton. *Strojirenstvi*, v. 25, No. 10, 1975, pp. 597-609 (Czech).*

The corrosion resistance of plain-carbon, copper-alloyed, and rust-protected low-alloyed structural steel in rural, urban, and industrial atmospheres is reviewed; data on the performance of metallic, organic, and combination coatings are tabulated and optimization of corrosion protection and service-life forecasting are discussed. Nomographs relate corrosion losses to the sulfur dioxide content and humidity of the atmosphere.

10. Electrochemical Method for Atmospheric Corrosion Testing of Metals. V. Kucera and E. Mattsson. *Proc. 7th Scand. Corrosion Congress*, 1975, pp. 202-217.

The title method consists of a technique for continuous measuring, recording and integrating of the current produced in cells on the surface of metals that are corroding in the atmosphere. The electrochemical cells used were of 2 types: galvanic, with electrodes of Cu and steel; and electrolytic, with electrodes of only 1 metal e.g. Cu, Zn, or steel. Exposure of the cells to the atmosphere yields currents of 10^{-10} - 10^{-3} A and these are measured, recorded, and integrated by the herein described apparatus. There was developed a relation between the cell current and the corrosion rate. The results are given for Zn-Zn, Fe-Fe, and Cu-Fe under various atmospheric conditions.

11. Environmental Exposure System for Studying Air Pollution Damage to Materials. J. W. Spence, F. D. Stump, F. H. Haynie and J. B. Upham. NTIS Report PB-240615, Environmental Protection Agency, January 1975, 46 pp.

Design features of a controlled-environment exposure system consisting of five chambers are described. The purpose of the environmental system is to provide simulated environments for conducting statistical experiments for determining pollutant damage to materials. Design features include independent controls for regulating temperature, relative humidity, and concentration of gaseous sulfur dioxide, nitrogen dioxide, and ozone. To achieve accelerated weathering, the system also includes a variable dew/light cycle that incorporates chill racks to produce dew and xenon lamps to simulate sunlight. Before initiating exposure studies, differences in lighting and pollutant distribution among the chambers were minimized to below 10 percent variations for 95 percent of the measurements.

12. Kinetics of the Atmospheric Corrosion of Low-Alloy Steels in an Industrial Environment. R. A. Legault, and A. G. Preban. Corrosion, v. 31, No. 4, April 1975, pp. 117-122.

It has been demonstrated that the natural atmospheric corrosion behavior of low-alloy steels in industrial environments can be accurately described by an equation of the form: $\Delta W = Kt^N$. Thus, reliable predictions of long-term behavior become possible, and a vehicle is provided for accurately assessing the effect on atmospheric corrosion behavior of alloying additions, processing variables, and differences in exposure environment.

13. Long-Range Transportation of Air Pollutants and Corrosion Effects. S. E. Haagenrud and B. Ottar. Proc. 7th Scandinavian Corrosion Conference, 1975, pp. 102-105.**

The results of a study of long-range transport of air pollutants in Europe is presented and is discussed with respect to the atmospheric corrosion of steels, aluminum, and zinc.

14. New Models of the Mechanism of Iron Oxidation. C. G. Nestler. Technik, v. 30, No. 7, 1975, pp. 456-457 (German).

The existing theories about the oxidation of iron is discussed, and it is concluded, that to understand these processes, it is important to know and to increase the knowledge about Fe_3O_4 and the oxyhydrate $FeOOH$. This involves research on lattice vacancies and transport mechanisms.

15. Properties of Rust on Weathering Resistant Steel After Full-Scale and Accelerated Testing. A. M. Shlyafirner, G. P. Yakubova, A. L. Golubev and N. I. Sotskov. Zashch. Met., v. 11, No. 2, 1975, pp. 200-204 (Russian).**

The electrochemical behavior of steels (1) 10KhNDP, (2) 10KhSND, (3) St 3 sp, and (4) St 2 kp, and the composition of rust formed were investigated. The contents of Cr, Ni, and Si in the rust were proportional to those in the base metal, but in the case of silicon it was

also effected by the dust content of the atmosphere. The copper presence was not determined, while phosphorus appeared only in the rust layer close to the metal, and the content of sulfur depended on its presence in the corrodent. The basic phases of rust were Fe_3O_4 , FeOOH , and FeSO_4 , but Fe_3O_4 was determined only after accelerated tests and only in a small amount after 3 years full-scale test on 10KhNDP. The polarizing curves determined in 0.1 N Na_2SO_4 after corrosion tests showed that the formation of rust decelerated the anode process; the completely passive state of 10KhNDP was reached after a 4 month's accelerated test, when a two-layer rust, consisting of Fe_3O_4 , was formed.

16. Role of Chlorine in β - FeOOH on Its Thermal Change and Reactivity to Sulfur Dioxide. T. Ishikawa and K. Inouye. Bull. Chem. Soc., Japan, v. 48, No. 5, 1975, pp. 1580-1584.

The state of chloride in β -ferric oxide hydroxide (β - FeOOH) was examined by X-ray diffraction, IR absorption, chemical analysis, DTA, and TGA. The adsorption of SO_2 was determined as a measure of the surface activity. No influence of chloride contained in the crystal appeared in the X-ray diffraction patterns and surface area. The absorption bands at 640 and 840 cm^{-1} in IR spectra showing the deformation vibration of the OH group diminished with the decrease of chloride content. It was shown that the path for β - FeOOH to transform into α - Fe_2O_3 by heating differentiates from the sample including more than 11.5 percent chloride/iron to one including less than 11.5 percent chloride/iron. This critical chloride content is equal to the amount of chloride when chloride fills up the characteristic tunnels existing in the β - FeOOH crystal. Chloride in β - FeOOH interferes both with the transformation into a α - Fe_2O_3 and the recrystallization of resultant γ - Fe_2O_3 . These effects were explained by the stabilization of the β - FeOOH structure by chloride in tunnels and the bonding between chloride and iron. The amount of chemisorbed SO_2 was lowered by chloride which was adsorbed on outer surfaces.

17. Sulfur Dioxide and Material Damage. D. G. Gillette. J. Air Pollution Control Assn., v. 25, No. 12, December 1975, pp. 1238-1243.

Whereas most estimates of material damage are based on industrial surveys, the estimates produced in this study were derived from material damage experiments and ambient air quality data. Air quality data on SO_2 were obtained from 200 or more monitoring sites primarily located in heavily populated or polluted areas. Material threshold damage function data were then compared with SO_2 levels, and an estimate of losses, as reflected in increased maintenance and replacement costs, was determined. Estimates of the total stock of various materials in use were derived from census and industry data and allocated geographically according to population. A substantial decrease in the ambient SO_2 levels, particularly in larger urban areas, has occurred during the past five years. From 1968 to 1972, the estimated amount of material damage from SO_2 in the U.S. decreased from \$900 million/yr to less than \$100 million. During this period, the estimated percentage of man made materials exposed to SO_2 levels exceeding the proposed secondary annual average standard (60 $\mu\text{g}/\text{m}^3$) and primary annual average standard (80 $\mu\text{g}/\text{m}^3$) in the U.S. fell,

respectively, from 20 percent to less than 5 percent and from more than 10 percent to less than 1 percent. Most of the present loss is attributed to corrosion damage of metallic surfaces that are normally exposed to the ambient environment.

18. The Influence of the Sulfur Dioxide Supply and the Relative Humidity on the Corrosion of Mild Steel. T. Sydberger and R. Ericsson. 7th Scand. Corrosion Congress, 1975, pp. 87-101.**

Mild steel specimens were exposed to atmospheres contg. SO_2 1, 10, and 100 ppm, and having relative humidities of 80-96%. Different flow rates, corresponding to SO_2 flow rates of 0.4-250 $\mu\text{g}/\text{cm}^2\text{h}$, were used. The specimens were then exposed to atmospheres having different relative humidities but contg. no SO_2 , and the resultant corrosion was studied by means of X-ray diffraction, infra-red spectroscopy, and thermogravimetric analysis. The main crystalline corrosion product was $\alpha\text{-FeOOH}$, and magnetite was not formed in detectable amounts. The results indicate the importance of flow rate with respect to corrosion. A drastic increase in corrosion rates after spraying the specimens with distilled water was observed.

19. The Semiconductive Property of Gamma-Ferric Oxyhydroxide. K. Kaneko and K. Inouye. J. Electrochem. Soc., v. 122, No. 3, 1975, pp. 451-452.

Gamma-ferric oxyhydroxide has a particularly sensitive and mobile structure. Baking and evacuation result in the formation of oxygen defects in crystals making the movement of electrons more facile. Changes in the conductivity of $\gamma\text{-FeOOH}$ were almost reversible with increasing and decreasing temperature.

1974

1. A Study of the Corrosion Effect of Atmospheric Pollution. E. Rothstadter and L. Halmay. Korrozios Figyelo. XIV evfolyam 1, szam, 1974 (Hungarian).

Data on aggressivity obtained at exposure stations in characteristic climatic areas--urban, country, and industrial ones--are presented. The aggressivity of the atmosphere was determined from the weight loss of carbon steel samples exposed 5 years ago and 14 years ago. The deviation between the two series of measurements may be related to the change in the pollution of the atmosphere of the area surrounding the particular exposure station.

2. Air Pollution Effects on Catastrophic Failure of Metals. J. Gerhard and F. H. Haynie. Environmental Protection Agency, EPA-650/3-74-009, November 1974, 33 pp.

The probable contribution of air pollution to the catastrophic failure of metal structures is a significant problem. Cited examples of failures and an economic analysis based on those failures indicates that injury and loss of life accompany between \$50 million and \$100 million annually in economic losses for the nation.

Although there is strong evidence that the effect exists, there has been no research to determine relationships between levels of particular pollutants and the occurrence of catastrophic failures of metals.

3. Atmospheric Corrosion. H. Eyring, B. Robertson, C. C. Chu, and T. Anderson. Proc. Nat. Acad. Sci. USA, v. 71, No. 2, February 1974, pp. 245-247.

A model of electrolytic corrosion is developed. It is shown that electrically conducting channels, threading through the oxide layer and connecting anodic and cathodic areas, obey the equation for a reactant being catalyzed by its product. The resulting autocatalytic reaction is compared with available experimental data and found to be widely applicable and capable of unifying many experimental observations.

4. Analyses of Some Suggested Mechanisms for Atmospheric Corrosion of Iron in the Presence of Sulfur Dioxide. J. R. Duncan. Werkst. Korros., v. 25, No. 6, 1974, pp. 420-424.**

The current theories of the atmospheric corrosion of Fe in the presence of SO_2 , that is, the acid regeneration cycle and the electrochemical model of K. Barton and Z. Bartonova, were examined based on experimental results. It was shown that no conflict occurs between these recent results and the electrochemical model as the main corrosion path.

5. Behavior of Low Alloyed Steel. K. Schwabe and W. D. Arnold. Proc. of the Fifth International Congress on Metallic Corrosion, Tokyo (Japan), National Association of Corrosion Engineers, Houston, TX, 1974, pp. 760-763.

Experiments conducted show that the anodically formed oxide layers on copper-alloyed steels are more corrosion protecting than the ones on unalloyed steel. This is due to an increase of copper and chromium in the layer. These same results, which were obtained from natural corrosion, apply to corrosion by SO_2 and sulfates.

6. Behavior of Rust and Rusted Steel Surfaces. G. K. Singhanian, B. Sanyal and J. N. Nanda. Proc. of the Fifth International Congress on Metallic Corrosion, Tokyo (Japan), National Association of Corrosion Engineers, Houston, TX, 1974, pp. 769-773.

The effects on the character of rust, of the initial weather conditions, the duration of exposure, and the wetting of metal specimens with electrolytes are discussed. Results show that the rust layer may be

protective or may promote corrosion depending on the nature of the rust rather than its thickness.

7. Correlation Between Corrosion Behavior of Steel and Atmospheric Pollution Data. F. H. Haynie and J. B. Upham. Corrosion in Natural Environments, ASTM STP 558, American Society for Testing and Materials, 1974, pp. 33-51.

An equation is derived from experimental data that relates the corrosion depth of easily corroded, enameling steel (carbon 0.019 and copper 0.028 percent) to the exposure time, the average relative humidity, the nitrate and sulfate in the particulates, and SO_2 . No significant changes were caused by differences of the average temperature, the average total suspended particulates, or the average nitrate. The corrosion data were obtained at 57 National Air Sampling Network sites.

8. Corrosion Aggressivity of Model Regions of Czechoslovakia. D. Knotkova-Cermakova, B. Bosek, and J. Vlckova. Corrosion in Natural Environments, ASTM STP 558, American Society for Testing and Materials, 1974, pp. 52-74.

A comprehensive research program was started in Czechoslovakia 5 years ago for a systematic investigation of the corrosion aggressivity of selected industrial regions. The corrosion tests were performed at 19 corrosion stations in the North-Bohemian model region. Principal technical metals were tested.

The characteristics of climate and air pollution and also the combined index of the corrosion aggressivity were suggested and numerically expressed.

The hyperbolic function has most closely approximated the law of the time-dependent course of the corrosion process of metals. The regression analysis was performed with the use of various forms of the climate characteristics, and the most favorable function was expressed.

A cybernetic model of the atmospheric corrosion process was suggested.

9. Corrosion of Metals in the Atmosphere. W. K. Boyd and F. W. Fink. MCIC-74-23, Battelle-Columbus Labs., Metals and Ceramics Information Center, Columbus, OH, August 1974, 77 pp.

The main corrosion characteristics of the commercial metals commonly employed for external applications are summarized. Some of the factors that affect metal behavior in general are discussed at the outset, but since each metal has a characteristic response to the corrosive constituents in external atmospheres, some of these factors are discussed again in the sections on the individual metals. Included in this report are sections dealing with carbon, weathering, and stainless steels, aluminum alloys, copper alloys, lead and lead coatings, and zinc and zinc-coated steel.

10. Design of a Laboratory Experiment to Identify the Effects of Environmental Pollutants on Materials. J. W. Spence and F. H. Haynie. Corrosion in Natural Environments, ASTM STP 558, American Society for Testing and Materials, 1974, pp. 279-291.

This paper describes an environmental system consisting of five exposure chambers and an experimental design for studying the effects of gaseous air pollutants (sulfur dioxide (SO_2), nitrogen dioxide (NO_2), and ozone (O_3)) on materials. Each chamber has the means for independent control of six environmental variables (temperature, relative humidity, etc.) as well as the unique feature of chill racks that regulate the formation of dew on the test specimens. An accelerated test is achieved by a dew-light (xenon lamp) cycle to simulate diurnal conditions. Statistical techniques (analysis of variance) were used to correct for differences in light and pollutant distribution within the chambers before initiating a statistically designed environmental experiment. To study the interactions of pollutants and other environmental variables that are likely to have significant effects on materials, a two-level factorial arrangement was selected.

11. Detection of the Extent of Corrosion Under Paint Films. C. G. Nestler. Technik, v. 29, No. 2, 1974, pp. 98-100 (German).

An ultrasonic technique has been devised for investigating the extent of rusting below paint films. Steel sheets, covered with 40 μm thick coatings of clear plastic, were used so that the results obtained could be compared with visual observation. For specimens >2 mm thick, a direct transmission method was used to determine the extent of rusting to an accuracy < 1 percent. An oblique technique was developed for sheets < 3 mm thick, using a 35° inclined probe head, and measuring the attenuation of the reflected signal. Agreement with direct observation was within 2 percent. It is not yet known what the effect of fillers and pigments would be.

12. Effect of Air Pollution on Materials and Technical Equipment. D. Knotkova-Cermakova, K. Barton, and B. Dolezel. Ochr. Ovzduš., v. 6, No. 6, June 1974, pp. 75-83 (Czech).

Adverse effects of air pollution on materials are reviewed. Metals are corroded by sulfur dioxide and solid particles containing salts. Such metals can be divided into four classes: immune, significantly passive, those corroded by oxides and hydroxide, and iron in which SO_2 stimulates rust. Sulfur dioxide is also a significant corrosive agent for polymers, either through direct reaction or as a stimulant of photochemical degradation. Other pollutants which adversely affect polymers are nitrogen oxides, organic substances which produce photolysis products, and solid pollutants such as dust and ash which affect physical properties.

Silicate construction materials are subject to extractive corrosion, chemical corrosion by salts, and decomposition by sulfuric acid. Ceramics lose their insulating properties due to surface deposits. The effect of pollution on the quality of metallic protective coatings depends on the chemical composition of the coating and on electrochemical reactions

between it and the metal being protected. Paint pigments react with SO_2 which lowers their effectiveness by two to three times in contaminated areas.

13. Effect of Alloy Composition on the Atmospheric Corrosion Behavior of Steels Based on a Statistical Analysis of the Larrabee-Coburn Data Set. R. A. Legault and H. P. Leckie. Corrosion in Natural Environments, ASTM STP 558, American Society for Testing and Materials, 1974, pp. 334-347.

In 1962 C. P. Larrabee and S. K. Coburn published an extensive collection of atmospheric exposure data showing the effect of variations in copper, nickel, chromium, silicon, and phosphorus content on the corrosion resistance of low-alloy steel. Two hundred and seventy steel alloys of different composition were exposed for 15-1/2 years at three separate locations representing industrial, semirural, and marine atmospheres. Among these experimental steel compositions there were five levels of copper concentration, two levels of nickel concentration, three levels of chromium concentration, three levels of silicon concentration, and three levels of phosphorus concentration represented. A statistical analysis of these data has been conducted and the results of the analysis are presented and discussed.

14. Effect of Structural and Environmental Factors in the Practical Use of Low-Alloy Weathering Steel. I. Matsushima, Y. Ishizu, T. Ueno, M. Kanazashi, and K. Horikawa. Proc. of the Fifth International Congress on Metallic Corrosion, Tokyo (Japan), National Association of Corrosion Engineers, Houston, TX, 1974, pp. 744-754.

The results of an experiment conducted to study extensively the effects of the structural factors on atmospheric corrosion are presented.

15. Electrochemical Technique for Determination of the Instantaneous Rate of Atmospheric Corrosion. V. Kucera and E. Mattsson. Corrosion in Natural Environments, ASTM STP 558, American Society for Testing and Materials, 1974, pp. 239-260.

The aim of this investigation was to develop a technique and equipment for the measurement of the instantaneous rate of atmospheric corrosion of metals. An electrochemical method was chosen for this purpose and a technique was developed for continuous measurement and recording of the currents generated in models of the electrochemical corrosion cells which occur on the metal surface when exposed to the atmosphere. Two types of cells were used, galvanic cells consisting of steel and copper electrodes and electrolytic cells consisting of only one type of electrode, namely, steel, zinc, or copper. In the latter type of cell an external emf was applied. The cell current was found to vary between 10^{-10} and 10^{-3} A in accordance with changes in climatic conditions, the changes being at least in qualitative agreement with changes in the rate of atmospheric corrosion as earlier reported in the literature. An inexpensive electronic integrator was developed for estimation of the accumulated quantity of cell current over a certain

period of time. This device integrates separately on two counters the amount of current during periods with low current and during periods with high current. A time counter also records the exposure time during which the current exceeds a chosen value. This time counter also records the exposure time during which the current exceeds a chosen value. This time counter can be used to measure the time of surface wetness, that is, that part of the period of exposure when the corrosion current is of practical importance. Efforts are now being made to find the quantitative relation between the cell current and the atmospheric corrosion rate. It is believed that the technique will prove to be a useful tool for the investigation of atmospheric corrosion in the laboratory as well as on test sites out of doors and in industrial applications.

16. Environment and Quality of Life. Literature Study on the Economic Consequences of the Damages and Annoyances Both in Materials and Vegetation and in Men and Animals Caused by Sulfur Dioxide Air Pollution. E. Lahmann. Commission of the European Communities, Luxembourg, September 1974, 150 pp. (German).

On account of its frequent occurrence in the atmosphere near the ground and its reactivity, sulphur dioxide (SO_2) is an essential contributor to negative effects of air pollution. Frequently economic damage is caused by SO_2 , especially to agricultural crops and to forests. With reference to human health its effects are principally combined with other air pollutants, especially particulates. The effects upon animals are of no practical or economic importance. The damage of sulphur dioxide upon materials has been proved beyond doubt. The economic consequences of air pollution in general and of SO_2 in particular are discussed only rarely in the relevant European literature. The existing gaps appears to be due to the uncertain nature of the subject as well as to a delay of research. Proposals for corresponding research programs are made. Most studies published on damages caused by air pollution do not refer to individual components, but to air pollution as a whole. The findings and estimates of costs incurred by air pollution have their origin mostly in the USA. Within the European Commonmarket comprehensive reports were available only from the UK, France, and Italy, but no one of these reports gives any estimates on the proportionation of costs caused by SO_2 alone. Some cost estimates have been made in Sweden on damages caused by SO_2 .

17. Kinetics of the Rusting of Iron in the Atmosphere. K. Barton, Z. Bartonova and E. Beranek. Werkst. Korros., v. 25, No. 9, 1974, pp. 659-663 (German).

Laboratory experiments using 0.12 percent carbon steel, were organized to describe the kinetics of active periods of atmospheric corrosion. It was found that below zero C the corrosion rate is independent of SO_2 content and humidity of the atmosphere. Above zero C it is controlled by reactions leading to formation of "sulfate nests" and hydrolytic rust. Simultaneous action of higher temperature (above 15 C) and larger amounts of water (above 100 g m^{-2}) decreases the accelerating effect of increasing SO_2 content. The corrosion rates determined are in good agreement with data calculated from long-term tests in natural environments.

18. Low Alloy Steels for Composite Highway Bridges - Effect of Sheltering on Corrosion. J. S. Hutchins and M. McKenzie. NTIS Report PB-239906, 1974, 42 pp.

The use in bridge construction of a steel requiring no maintenance painting becomes increasingly desirable. At seven test sites throughout the country, the corrosion of a low alloy steel and a special mild steel have been compared in both open and sheltered conditions over a two-year period. Meteorological and atmospheric pollution data were also collected.

19. Mechanism of Formation of Iron Oxide and Oxyhydroxides in Aqueous Solutions at Room Temperature. T. Misawa, K. Hashimoto, and S. Shimodaira. Corros. Sci., v. 14, No. 2, 1974, pp. 131-149.

The mechanism of formation of green rusts, Fe_3O_4 , $\alpha\text{-FeOOH}$, $\beta\text{-FeOOH}$, $\gamma\text{-FeOOH}$, $\delta\text{-FeOOH}$, and amorphous FeOOH in aqueous solution at room temperature was studied to better understand the atmospheric rusting of iron and steel. The formation processes upon which end-products are determined are strongly affected by the oxidation rate, pH, and the structure and composition of the initial and intermediate species of iron. A systematic diagram of the formation process of the above species is presented, in which both dissolved and solid compounds of iron are included.

20. Selecting Testing Conditions Representative of the Atmospheric Environment. J. F. Stanners. Corrosion in Natural Environments, American Society for Testing and Materials, ASTM STP 558, 1974, pp. 23-32.

The main environmental factors that affect atmospheric corrosion of metals are examined and their range and distribution are related to steel utilization. From the data available, recommendations are made for the selection of exposure sites in Great Britain likely to be more representative of conditions in which steel is used than are present sites. A method is suggested for examining pollution data in this context. The implications for natural atmospheric exposure testing are discussed.

21. The Economic Damages of Air Pollution. T. E. Waddell. NTIS Report PB-235701, 1974, 156 pp.

Air pollution has a variety of effects on materials--the corrosion of metals, the deterioration of materials and paints, and the fading of dyes. There have been a number of attempts at estimating the resultant economic losses due to those detrimental effects of air pollution.

22. The Economics of Clean Air in Perspective. F. H. Haynie. Materials Protection and Performance, v. 13, No. 4, April 1974, pp. 33-38.

This paper places the economics of providing cleaner air in perspective by emphasizing some of the tangible benefits to be received. The Materials Branch, National Environmental Research Center, Research Triangle Park, North Carolina, has determined damage functions for air pollution effects on materials and estimated the resulting economic loss to the nation.

23. The Mode of Initial Reaction of SO_2 at a Metal Surface. J. R. Duncann and D. J. Spedding. Corrosion Science, v. 14, No. 4, 1974, pp. 241-249.

The mode of initial reaction of sulfur dioxide at a metal surface exposed to the atmosphere can be explained better by a model based on specific adsorption of the sulfur dioxide at an electrolyte solution/metal oxide interface than by a model based on reaction with an electrolyte layer formed at the exposed metal surface. Sulfur dioxide adsorption at discrete areas of uptake and at freshly cut edges, previously reported on iron, also occurred on copper, aluminum, and stainless steel samples; adsorption was found to increase as relative humidity was increased. The specific adsorption model was found particularly useful in explaining the differential uptake of sulfur dioxide on metal surfaces; the quantities necessary to explain the fate of the adsorbed sulfur dioxide; the kinetic data found for sulfate formation on iron and zinc surfaces.

24. The Relation Between the Corrosion Rate of Steel and the Fallout Rate of Various Pollutants. S. Luckat. Staub. Reinhalt. Luft, v. 34, No. 6, June 1974, pp. 209-213 (German).*

The corrosion rate of DIN 1623 steel was correlated with the measured ambient concentration of pollutants over a 12-month period. The steel samples (1 mm sheets, 50 x 100 mm) were exposed for 14 days before analysis and the pollutants measured over the same period. SO_2 , SO_3 , H_2S , and H_2SO_4 were analyzed together and reported as SO_2 , F compounds as F and Cl compounds as Cl. The corrosion rate correlated closely with the SO_2 measured, but not with the other pollutants. During the summer the corrosion rate was low and virtually independent of the site because of the lower relative humidity.*

25. The Use of Weather and Climatological Data in Evaluating the Durability of Building Components and Materials. L. W. Masters and W. C. Wolfe. NTIS REPORT COM-74-50841/7, August 1974, 102 pp.

The durability of building components and materials is dependent, to a large extent, on the in-service environment to which they are subjected in service. Thus, the prediction of durability requires knowledge of the service environment. Weathering factors, which comprise one group of environmental factors, are the subject of this report. The objectives of this report are to indicate how, in the present state of knowledge, weather and climate data can be used to aid in quantifying weathering factors so that durability tests for building components and materials may be designed.

26. Various Factors Affecting Atmospheric Corrosion of Steels. J. Satake and T. Moroishi. Proc. of the Fifth Internat. Congr. on Metallic Corrosion, Tokyo (Japan), National Association of Corrosion Engineers, Houston, TX, 1974, pp. 744-754.

Atmospheric exposure tests were conducted to investigate the correlation between atmospheric corrosion behavior of steels, environmental factors and rust structure. Figures show the effect of SO_2 and sea salt on corrosion loss after a period of exposure of one to five years. The compactness of the rust layer mainly controls the atmospheric corrosion rates of the steels. The distribution of alloying elements and their variations in and out of pits were studied to investigate the possible influence of those elements on the protectiveness of the rust layer.

27. Weather Factors Affecting Corrosion of Metals. P. J. Sereda. Corrosion in Natural Environments, ASTM STP 558, American Society for Testing and Materials, 1974, pp. 7-22.

Various weather factors are assessed in relation to corrosion of metals. Published data are discussed and new results presented to show that time-of-wetness is a very important factor and that reasonable values may be obtained from analysis of meteorological records. These are applicable for predicting long-range corrosion effects. For short-term corrosion, data must be collected for the particular exposure conditions. Results are presented to show the effect of orientation on time-of-wetness, and recommendations are made for increasing this type of study.

A summary of data on pollution by SO_2 in major cities of Canada is presented and the distribution in Metro Toronto given. It indicates that pollution by SO_2 has been decreasing in many areas of the world. The effects of chlorides, corrosion products, and temperature are also discussed.

1973

1. Accelerated Atmospheric Corrosion Tests in Polluted Air. Influence of Dew-Cycle on Steel in SO_2 Environment. S. Yamasaki and Y. Yokoi. Corrosion Engineering, 1973, v. 22, No. 4.

The similarity between results of dew-cycle corrosion tests and the results of field exposure has been evaluated by comparing the corrosion rate of mild steel with that of weathering steel at several dew-cycle conditions in 20 ppm SO_2 . It was known that both the similarity and acceleration of tests are, particularly in the case of steel, largely dependent on the drying process. An attempt was made to convert the corrosion quantity versus testing time curve, which was generally used, into the curve of corrosion quantity versus total dewing time, that is, testing time minus drying time. If Fe(II) rust, formed during wet or dew period, is sufficiently oxidized to Fe(III) rust in the process of drying, the slope of corrosion quantity versus total dewing time should become sharper. This is because the reduction of Fe(III) rust to Fe(II) during

the succeeding dew period induces the corrosion of steel. The period 30 minutes of light dewing (temperature of specimen: 35 C; atmosphere: 37 C, 100 percent RH) showed a good similarity between the test results and the results of field exposure. The corresponding optimum drying period seemed to exist between 30 and 60 minutes.

2. Atmospheric Corrosion of Carbon Steels. E. Beranek and K. Barton. Werkst. Korros., v. 24, No. 5, 1973, pp. 372-378 (German).

The corrosion of steel sheets containing C 0.09, Mn 0.27, Si <0.01, P 0.023, S 0.038, and Cu 0.06 percent in an urban atmosphere (Prague) was studied during 3 years in the open air and under a shelter against solar irradiation and rain. A relation was established between meteorological data and the process of rusting in the atmosphere. A limit for the SO₂ absorption was found and the aggressivity of the atmosphere for steel was determined. It depended on the slope of the accumulated monthly corrosion versus time curve.

3. Atmospheric Corrosion of Plain Carbon and Low-Alloy Steels in Marine, Rural, and Industrial Atmospheres. K. Bohnenkamp, G. Burgmann and W. Schwenk. Stahl Eisen, v. 93, 1973, pp. 1054-1060 (German).

The corrosion of a number of carbon and low-alloy steels containing various Cu contents in marine, rural, and industrial atmospheres was investigated in a series extending more than 8 years. Results are expressed in log plots of mean integral weight loss in kg/m²-yr as a function of exposure time and an evaluation of regression curves $v_t = k \times t^{-n}$, where v_t is the decrement rate of the weight loss, t is the time, and n (approximately 0.5) is a coefficient representing the rate-controlling mass transport through the rust layer. For very short and very long exposures, a linear time law applies. In long exposures, the thickness of the rust layer was nearly independent of the steel grade, location, and time of exposure. The protection by the rust increased with aging. The rate of the phase-boundary reaction, v_0 , over a short time is a constant at the same location and nearly independent of steel composition, but it increases with the increasing aggressivity of the atmosphere. For a specimen enameled on one side, the weight-loss rate was caused by a longer action of moisture, and corrosive sulfates and chlorides.

4. Behavior of Rust and Rusted Steel Surfaces. G. K. Singhania and B. Sanyal. Br. Corros. J., v. 8, No. 5, 1973, pp. 224-229.

Mild steel samples, exposed to the atmosphere for 12 months starting in the dry or wet season of Kanpur, showed different corrosion patterns but reached the same corrosion rate at the end of 12 months. The weight loss of dry samples exposed to the atmosphere for 35 days was greater than that of samples wetted (washed) daily with water and smaller than that of samples wetted daily with sulfate or chloride solution. The adsorption of sulfur dioxide on rust continued beyond a 96 hour test period, but maximum corrosion occurred on a sample in contact with rust exposed to sulfur

dioxide for only 48 hours. Prerusted steel samples resisted attack by sulfur dioxide to a degree that depended on the length of pretreatment and not on the thickness of the rust. Corrosion rates of clean and prerusted samples temporarily exposed to sulfur dioxide showed that the sulfur dioxide affects the corrosion rate of rusted, but not of clean, samples at low temperatures (18°C) and relative humidities.

5. Bimetallic Corrosion Effects on Mild Steel in Natural Environments. K. E. Johnson and J. S. Abbott. Brit. Steel Corp., CEL/CH/23/73, 1973, 12 pp.

Corrosion rates were determined for mild steel and various metals and alloys when mild steel-metal or alloy couples were exposed to industrial, urban/rural, and marine atmospheres, natural water, and sea water. The relative order of effect of these metals and alloys on the corrosion rate of mild steel in each environment is reported.

6. Can Ammonia Injection Into Waste Gas be a Successful Means for Protecting the Environment? R. Chrusciel. 42nd Internat. Ind. Fair (Posen 6/10-19/73), VDI (Ver-Dtsch. Ing.) Z., v. 115, No. 8, June 1973, pp. 19-23 (German).

In previously published studies supported by the Polish Ministry of Mining and the Energy Economy and carried out at various institutions, guinea pigs, and tops of several plant varieties (for example, clover and buckwheat), and stainless steel 35 specimens were exposed to atmospheres containing various concentrations of sulfur dioxide, with and without neutralization by ammonia. The effectiveness of the ammonia in reducing the damage to plants, animals, and steel, and the finding that the fallout of ammonium salts would not be excessive under favorable weather conditions, led to the construction of pilot-scale and full-scale industrial powerplants fitted with ammonia injection units on the stacks. The duration of injection is governed by the weather conditions.

7. Characterization of Bridge Locations by Corrosion and Environmental Measurements - First Year Results. J. S. Hutchins and M. McKenzie. Report No. TRRL-LR-550, Transport and Road Research Lab., Crowthorne, England, 1973, 29 pp.

Climatological and air pollution factors greatly affect the corrosion damage to steel highway bridges. First results of a program to define quantitative criteria by which the potential corrosivity of a prospective bridge location can be assessed are given. At seven sites throughout the country, the corrosion rates of hot-rolled mild steel, low-alloy steel, and zinc, are being measured under both open and sheltered exposure. Meteorological and air pollution data are also being collected. A mobile test rig was developed which can be easily transported to any prospective bridge location. From the first year's results, it is apparent that sheltered test specimens give a much closer indication of the corrosivity under a bridge deck than open exposure specimens. Of the environmental

factors, atmospheric chlorides and sulfur compounds are the major cause of variations in corrosion rate.

8. Concept of "Corrosion Aggressivity" of the Atmosphere With Respect to Carbon Steels. E. Beranek and K. Barton. *Werkst. Korros.*, v. 24, No. 5, 1973, pp. 372-378 (German).

On the basis of exposure tests on 0.009 percent carbon steel sheet, it is shown that a relation may be derived between meteorological data and atmospheric corrosion which shows the controlling effects of the duration of wet periods and of the intensity of SO₂ attack. Qualitative conclusions are drawn concerning the effect of SO₂ concentration during initial exposure on the protective character of the rust formed, and concerning the finding that there is a critical concentration of SO₂ below which its effect is not important.

9. Corrosion Caused by Perspiration. G. A. Tret'yakova and V. P. Barannik. *Zashch. Metal.*, v. 9, No. 6, November-December 1973, pp. 715-717 (Russian).

The corrosion of a number of metals (C and stainless steels, Cu, Cu alloys, Zn, Cd, etc.) as a result of contact with the human hand is discussed. The perspiration of the hand contains such elements as Na, K, Ca, Mg, and I, together with urea, amino acids, etc., and hence may constitute a very corrosive medium, particularly in the hotter months of the year. The corrosion often appears as almost perfect fingerprints. Alloys of copper are more susceptible to this corrosion than copper itself; aluminum alloys corrode slowly with the formation of loose grey deposits; chromium coatings are very resistant to perspiration but the latter tends to penetrate through the pores of the chromium and corrodes the underlying metal.

10. Cost of Air Pollution Damage - A Status Report. L. B. Barrett and T. E. Waddell. Environmental Protection Agency, NTIS Report PB 222-040, 1973, 85 pp.

Cost estimates of air pollution are developed for effects on human health, vegetation, materials, and residential property values. Estimates are not given for damage to animals and to aesthetic aspects of the environment.

11. Crystalline and Amorphous Primary Products During the Rusting of Metallic Iron in Sulfur Dioxide-Containing Atmospheres at Different Humidity. E. D. Franz. *Werkst. Korros.*, v. 24, No. 7, 1973, pp. 598-601 (German).**

The formation of sulfides, sulfites, sulfates, thiosulfates, and S occurs in the corrosion of iron in sulfur dioxide-containing atmospheres. Characteristic differences were dependent on the atmospheric humidity. The reaction did not take place beyond the FeS stage at 77 percent

relative humidity and no reaction was observed at 50 percent relative humidity.

12. Discrete Areas of SO_2 Adsorption from the Atmosphere onto Iron. J. R. Duncan, D. J. Spedding, and E. E. Wheeler. Corros. Sci., v. 13, No. 1, January 1973, pp. 69-72.*

In an experimental study in which sulfur-35 dioxide was adsorbed from the atmosphere onto iron surfaces which were not visibly rusted at 70 pct or 95 pct relative humidity, autoradiographs of the samples showed major variations in the degree of uptake of sulfur dioxide over the metal surface, with most of the sulfur dioxide centered in specific areas up to 0.5 mm in diameter. Surface features large enough to cause these differences were not visible under the electron or light microscope. A possible reason for the formation of these discrete areas of adsorption might involve fracture of the oxide layer at a submicroscopic point, allowing adsorption of the sulfur dioxide at a different type of iron oxide form from that on the outside surface; and repair of the oxide layer during normal growth, obscuring the imperfection from microscopic detection.

13. Influence of the Inclination and Direction of Specimen Surface on Atmospheric Corrosion of Steels. T. Moroishi and J. Satake. Tetsu To Hagane, v. 59, No. 1, 1973, pp. 125-130 (Japanese).**

The corrosion rate of a steel and the morphology of the rust are influenced by the inclination and direction of the steel surface exposed to the atmosphere. Sheets of a C steel and low-alloy steel, one side of the surfaces of which was coated by resin paint, were positioned at 0, 30, 60, and 90 degrees to the horizontal, facing skywards and groundwards. Atmospheric exposure tests were carried out for 2 years. Corrosion rate of steels and the sulfate and retained water content of the rust layer were studied. The corrosion rates of the groundward surfaces were greater than those of the skyward surfaces and decreased with increasing degree of the surfaces. Corrosion rates of the skyward surfaces positioned horizontally and vertically were greater than those of the inclined surfaces. The sulfate content of the rust could explain the dependency of the corrosion rate of the groundward surfaces on the inclinations. The corrosion of the skyward surfaces related to the water-retaining property of the rust layer shows the same dependence on the exposure inclinations as the corrosion rates.

14. Initial Reactions of SO_2 After Adsorption on to Metals. J. R. Duncan and D. J. Spedding. Corrosion Science, v. 13, 1973, pp. 881-889.

An electrophoretic method for separation of labeled corrosion products from metals exposed to atmospheres containing natural concentrations of $^{35}\text{SO}_2$ has been developed. Using this method, it was found that on iron and zinc such products are exclusively sulphur (IV) species and sulphate. The conversion of S(IV) to S(VI) on both iron and zinc was found to have a half-life of approximately 24 hours.

The implications of these results are discussed with respect to a different chemistry of surface electrolyte layers from that of bulk solutions.

15. Investigations of the Atmospheric Corrosion of Plain Carbon and Low Alloy Steels in Industry, Country, and Sea Air. K. Bohnenkamp, G. Burgmann, and W. Schwenk. Stahl Eisen, v. 93, No. 22, 1973, pp. 1054-1060.

Natural corrosion of three steels with 0.10, 0.18, and 0.27 percent copper was investigated in industry air, on the test stands of the Verein Deutscher Eisenhüttenleute. Natural corrosion of a high-strength and a weather-resistant steel and various unalloyed and low alloy steels was investigated in sea air, country air, and industry air. The results were evaluated by means of regression analysis. The influences of the investigational procedure and the corrosion processes are discussed.

16. Mechanisms of Atmospheric Corrosion. A. Bukowiecki. Proc. Congr. Int. Union Electrodeposition Surface Finish. (8th-1972), 1973, pp. 14-21 (German).

The atmospheric corrosion of steel is reviewed. The concept of critical humidity, deliquescence of salt deposits in relation to corrosion, and metal attack by acid vapors are discussed.

17. Role of the Alloying Elements at the Steel/Rust Interface. R. Bruno, A. Tamba and G. Bombara. Corrosion, v. 29, No. 3, March 1973, pp. 95-99.

Three low alloy steels and an ordinary carbon steel were investigated as to the distribution of the alloy elements (Cu, Cr, P, Ni) in rust coverings produced either by weathering or by slight anodic oxidation. Electron microprobe examinations of rust showed, besides an overall enrichment in the alloy elements, the presence of sharp concentration peaks in layers some ten μm wide. The more resistant the steel to atmospheric corrosion, the higher the rust-to-steel concentration gradient and the closer the concentration peaks to the steel/rust interface. Corrosion potential and polarization measurements in 0.1M Na_2SO_4 on rusted specimens evidenced a marked effect of the interfacial enrichment in increasing the anodic polarizability and the tendency to a coverage passivation. This leads to looking upon the corrosion generated steel/rust interface as directly contributing, in addition to the rust itself, to the self protection of low alloy steels during atmospheric corrosion.

18. Studies of the Atmospheric Corrosion of Metals and Anticorrosive Coatings in Japan. Comparison of Observed and Calculated Values. Research Group on Corrosion Protection of Steel Structures. Corrosion Engineering, v. 22, No. 3, 1973.

Equations have been proposed which express corrosion rates (Y , mdd) of carbon steel in atmospheres as a function of atmospheric factors, that is, temperature (T , $^{\circ}\text{C}$), relative humidity (RH , percent), amount of rainfall (P , mm) and sulfur dioxide (SD , mdd) and chloride (C , ppm) content. Data used for multiple regression analysis were based on atmospheric exposure test results in the first year at 43 locations carried out by the authors as well as by other investigators. The equations developed are $Y = 4.15 + 0.88 T - 0.073 RH - 0.032 P + 2.193 C + 4.921 SD$ for inland and industrial atmospheres and $Y = 5.61 + 2.754 C + 6.155 SD$ for marine atmospheres. The results clearly show that while the SO_2 content is the most important factor, the effects of temperature and relative humidity cannot be neglected in developing corrosion equations.

19. The Effect of Alloying Elements on Atmospheric Corrosion of High Tensile Strength Steels. T. Moroishi and J. Satake. Journal Iron Steel Inst., Japan, v. 59, No. 2, 1973, pp. 293-300.

High tensile strength steels used for outdoor construction require a good atmospheric corrosion resistance. The specimens of high tensile strength steels containing various amounts of C, Si, Mn, Cr, Ni, Mo, Ti, Nb, Zr, B, and Cu were exposed to the atmosphere at Amagasaki and Kitakyushu up to five years. The effects of the alloying elements on the atmospheric corrosion resistance of the steels were analyzed by means of a multiple regression analysis. Corrosion rates of the steels are expressed by the equation: $W = kt/(n+t)$, where W = corrosion loss (μm), t = exposure time (year), and k, n = constants. k and n are given by the following equations:

At Amagasaki:

$$k(\mu\text{m}) = 182.2 - 54.7\text{Si} - 41.6\text{Cr} - 11.1\text{Ni} - 87.0\text{Mo} - 39.8\text{Cu} - 51.2\text{Nb}$$

$$n(\text{year}) = 2.46 - 0.98\text{Cr} - 1.20\text{Mo}$$

At Kitakyushu:

$$k(\mu\text{m}) = 247.9 - 106.6\text{Si} - 28.4\text{Cr} - 27.5\text{Ni} - 65.4\text{Mo} - 41.2\text{Cu} - 7071\text{B}$$

$$n(\text{year}) = 2.90 - 1.24\text{Si} - 0.74\text{Mo} - 42.50\text{P} - 77.64\text{B} - 0.32\text{Cr}$$

where Si, Cr, etc. indicate the contents of the alloying elements in weight percent. The effects of the alloying elements on the pitting depth were also analyzed; Si, Ni, and Cu reduced the depth of pits.

20. The Effect of Relative Humidity on Adsorption of Sulphur Dioxide Onto Metal Surfaces. J. R. Duncan and D. J. Spedding. Corros. Sci., v. 13, 1973, pp. 993-1001.

The influence of relative humidity and corrosion products on the uptake of atmospheric sulfur dioxide was studied on the basis of literature values and new experimental results obtained in the continuous flow of air at 65-100 percent relative humidity and 50-300 $\mu\text{g}/\text{cu m}$ of sulfur dioxide over 0.012 mm and 0.010 mm thick iron and zinc foils. Published results showed that a critical humidity of 94 percent at 25°C exists for the self-dissolution of manganese sulfate, which could account for both the increased uptake of sulfur dioxide and the acceleration in uptake rate on iron containing sufficient manganese. Desorption of iron after its removal from the sulfur dioxide atmosphere was irregular.

21. The Influence of Carbon Particles on the Corrosion of Iron in a Humid, Sulfur Dioxide-Containing Atmosphere. R. Ericsson, B. O. Heimler, and N. G. Vannerberg. *Werkst. und Korrosion*, v. 24, 1973, p. 207.

Iron samples covered with a thin layer of activated carbon have been exposed to humid atmospheres containing sulfur dioxide under controlled conditions. The increase in weight has been determined as a function of the time of exposure. An increased rate of corrosion of samples covered with a thin layer of activated carbon, compared with samples without carbon, has been observed only at low relative humidities only.

22. The Influence of Sulfite Ions on Pitting Corrosion of Stainless Steels. A. Luffkin. *Anti-Corros. Methods Mater.*, v. 20, No. 7, July 1973, pp. 3-8.

The influence of sulfite ions on pitting corrosion of stainless steels was studied by finding the rupture potentials of samples of types AISI 430, 316, and 304 stainless steels in media containing both sulfites and chlorides. The actions of sodium hydrosulfite, sodium thiosulfate, and sulfur dioxide, and sulfuric acid on steel were studied, and the effects of pH value on the oxygen reduction potential, as well as the chrono-potentiostatic conditions and comparative rupture potentials, were also examined. Sulfuric anhydride and the sulfites were found to intervene in the pitting corrosion of stainless steels by acting as cathodic depolarizing agents. The experimental results indicate an initial partial oxidation which forms sulfuric acid, dropping the pH and thus promoting the reduction of the remaining sulfur dioxide. Combinations of sodium chloride with sodium hydrosulfite or thiosulfate were found to be particularly reactive. Molybdenum steels were little affected by sulfur dioxide. These findings are of interest in relation to the effects of atmospheric sulfur dioxide on architectural stainless steel.

23. The Role of Aerobic Bacteria in Metal Corrosion. J. Brison. *Corrosion, Traitements, Protection, Finition*, v. 21, No. 4, 1973, pp. 242-247 (French).

Aerobic bacteria that produce acids, NH_3 , amines, H_2S , etc., can theoretically participate in corrosion as do anaerobic bacteria. In practice, they inhibit corrosion, and there is a relationship between protective power and their respiratory activity. If oxygen content is below a certain level, this protection stops, the anaerobic bacteria take over, and corrosion rapidly appears.

24. The Role of Coatings in Corrosion Prevention. Future Trends. V. Ashworth and R. P. M. Proctor. *Journal of the Oil and Colour Chemists Association*, v. 56, No. 10, October 1973, pp. 478-489.

The authors describe the complex electrochemical interaction between a metal and its environment which leads to corrosion, and also the other factors affecting corrosion (chemical engineering factors: heat and mass

transfer; metallurgical factors: microstructure and alloy composition; engineering factors: absorption, film growth and environment composition). The approaches to corrosion prevention: (1) design, (2) materials selection, (3) environmental control, (4) anodic and cathodic protection, and (5) protective coatings are outlined to put into perspective the present role of coatings and paints in corrosion prevention. The possible future trends in corrosion prevention are discussed. The authors conclude that metallic coatings will be replaced by organic and conversion coatings and corrosion inhibitors. Conventional coatings may be replaced by specially designed systems with better adhesion, coherence, and heat transfer.

1972

1. A Microscopic Study of Steel Surfaces Exposed to a Humid SO_2 -Containing Atmosphere. B. O. Heimler and N. G. Vannerberg. Corros. Sci., v. 12, 1972, pp. 579-582.

Electropolished and etched steel samples were exposed to a humid, sulphur dioxide-containing atmosphere under controlled conditions. The surface structure of the samples and the distribution of the points of attack after exposure were studied with a scanning electron microscope.

2. Analyzing Atmospheric Corrosion. J. B. Mohler. Pollut. Eng., v. 4, No. 7, 1972, pp. 28-29.

The protection of metals from pollution-caused corrosion: rates determined by the ASTM for the atmospheric corrosion of metals due to sulfur dioxide; a comparison of the corrosion rates of steel and zinc as measured at 45 test sites throughout the world; the corrosion of other metals; and methods of solving atmospheric corrosion problems are described.

3. Atmospheric Corrosion Behavior of Stainless Steels and Nickel Alloys. T. E. Evans. Proc. 4th Int. Congr. Metal. Corros. (1969), National Association of Corrosion Engineers, Houston, TX, 1972, pp. 408-418.

Eleven commercial stainless steels and nickel alloys with dull and/or polished finishes were exposed for 10 years at Birmingham, England. Four were also tested for 2.5 to 3 years at 14 diverse sites. Corrosion area, weight loss, and pitting were determined. Type 316 stainless steel resisted corrosion except in the presence of sea spray or pollution. Type 304 was satisfactory, but type 430 rusted.

4. Atmospheric Corrosion of Iron-Copper Alloys and Copper-Containing Steels. D. Fyfe, C. E. A. Shanahan, and L. L. Shreir. Proc. 4th Int. Congr. Metal Corros. (1969), National Association of Corrosion Engineers, Houston, TX, 1972, pp. 399-407.

High-purity iron, iron-copper, and iron-copper-steel alloys were used to study the effect of copper, steel, and copper plus steel on atmospheric corrosion of iron in industrial, rural, and rural-marine environments. Mild steel and copper steel were tested to show the effects of copper addition on common steel compared with iron. Specimens were exposed for 4, 12, 24, 48, and 67 weeks and the total rust, adherent rust, and weight loss determined. Rust structure studies were carried out by scanning electron microscopy. Copper additions to pure iron had only a small beneficial effect compared with that when steel was present in the alloy. This is explained by the deleterious effect of steel removed by precipitation of S^{2-} ions from the rust cell electrolyte as CuS .

5. Atmospheric Corrosion of Steels and Their Rust Structure. J. Satake and T. Moroishi. Sumitomo Kinzoku, v. 24, No. 1, 1972, pp. 39-49 (Japanese).

The distribution of elements in the rust layer formed on low-alloy steels after several periods of exposure in industrial and rural atmospheres was investigated by microscopy and electron-probe microanalysis. The rust layer in large pits contains Cu, P, and Cr. Chromium and phosphorus concentrate around defects in the rust. The rust layer on the flat surface surrounding large pits and also the surface layer above large pits show no evidence of localized concentration of copper and phosphorus and little carbon is found in it. Silicon, the main constituent of the rust, has been found in these parts of the rust, but none in the pits. It is supposed that Cr, P, and Cu produced by corrosion presumably form far less soluble compounds than Fe^{++} and are likely to precipitate in the pits, while Fe^{++} diffuses from the pits and precipitates on the outer surface. The H_2O permeability of rust layers was evaluated by impedance measurement of the rusted-specimen electrode in 0.1M $NaBO_2$ aqueous solution. The resistance of the rust layer decreases with immersion time as the solution penetrates into the rust and finally attains a steady state. Initial and final values of the resistance and also the time necessary to reach the steady state increases with increasing periods of atmospheric exposure and are larger for low-alloy steels than for carbon steel at the same exposure time. A linear relation has been confirmed between atmospheric corrosion rates and reciprocals of the final resistances and in some cases, initial values, which provide a measure of the porosity of the rust layer. It is supposed that the corrosion rate depends on the time of wetness, which determines the size of the area on the steel surface where the water penetrates the pores and corrosion begins. The paths through which rain water permeates the rust layer must be clogged by precipitation of compounds of Cr, Cu, and P that are less soluble than iron compounds.

6. Distribution of Alloying Elements in Rust Layers Formed Naturally on Corrosion Resistant Low Alloy Structural Weathering Steel. J. B. Horton, M. M. Goldberg, and K. F. Watterson. Proc. 4th Int. Congr. on Metal. Corros. (1969), National Association of Corrosion Engineers, Houston, TX, 1972, pp. 385-389.

Samples of Mayari R steel alloyed with low percents of C, Mn, P, S, Si, Ni, Cr, and Cu were allowed to weather for 5 yers, some in a severe marine atmosphere and others in a moderate industrial atmosphere. The concentrations of the alloying elements were measured using the ion surface analyzer. The results show that the alloying elements are distributed nonuniformly throughout the rust layers for samples at both sites. Those elements which function beneficially in the rust layer to protect the steel, do so either in the electrolyte at the metal surface or within the structure of the rust itself.

7. Effect of Weathering on the Electrochemical Behavior of Steels. R. Bruno, G. Agabio and G. Bombara. Brit. Corros. J., v. 7, May 1972, pp. 122-125.

A potentiodynamic anodic behavioral study was made of a 0.2 percent carbon mild steel and variants containing 0.204 percent Cu, 0.278 Cu-0.095 percent phosphorus, and 0.6Si-0.1P-0.375Cu-0.54Cr-0.26 percent Ni in 0.1M Na₂SO₄ as regards the protectiveness of early weathering patinas. The property of slow-rusting steels being able to build up a protective rust, which ennoble the metal-oxide interface, is significant only on weathering surfaces. Largely irrespective of the method and the extent of weathering, it is upon weathering that contributory alloying elements, by means of selective enrichment at the metal surface, can affect the thermodynamics and kinetics of the steel electrode during atmospheric corrosion. Corrosion potential measurements on weathered electrodes can give useful information about the surface ennoblement and the relative stability of oxide layers; a more significant differentiation in kinetic terms, related to coverage passivability, can be derived rapidly from simple potential sweep techniques. Critical passivation currents, potentials, and charges thus obtained can provide good relative evaluation indexes of weatherability. In view of the apparent consistency of these data with the results of extended exposure tests, such techniques are a promising research tool, not indeed for predicting service performance quantitatively, but for screening developmental alloys for atmospheric use.

8. Electrochemical Studies on Corrosion of Mild Steel by Sulfur Dioxide. G. K. Singhanian, S. K. Roy, S. N. Pandey and B. Sanyal. Labdev, Part A, v. 10, No. 2, 1972, pp. 82-84.*

Cathodic polarization of mild steel was studied by using the potentiokinetic method with different concentrations of SO₂ solution. Sulfur dioxide acts as a depolarizer enhancing the corrosion rate. The effectiveness of the depolarization depends upon the concentration and the extent of stirring, and is believed to be due to the reduction of sulfur dioxide rather than the low pH of the solution.

9. Hot-Dip Galvanized Steel Sheet and Its Corrosion Resistance. N. Dreulle and P. Dreulle. Galvano, v. 41, No. 427, 1972, pp. 867-871 (French).

The reaction between zinc and iron during the galvanizing process, the reaction of zinc during atmospheric corrosion, and the effect of the reaction products on the protection of steel are reviewed. Corrosion rates in geographical areas of France with varying atmospheric conditions are given.

10. Influence of Humidity and Contamination by Sulfur Dioxide on the Corrosiveness of Madrid Atmosphere on Steel. S. Feliu, M. A. Guillen and P. F. Manzano. Corros., Trait. Prot., Finition, v. 20, No. 7, November 1972, pp. 474-482 (French).

The part played by relative humidity (RH) in the atmospheric corrosion of steel is shown. The combined effect of humidity and contamination by sulfur dioxide on steel corrosion is serious only when a given monthly contamination level is reached and, simultaneously, the number of hours per month of $RH > 70$ percent exceeds a minimum given value.

11. Kinetic Influence of Sulfur Dioxide and Humidity in Atmospheric Corrosion of Steel. K. Barton, J. Honzak and Z. Bartonova. Proceedings 4th Int. Congr. on Metallic Corros. (1969), National Association of Corrosion Engineers, Houston, TX, 1972, pp. 425-428.*

A mechanism is proposed for the corrosion of iron in the presence of sulfur dioxide as follows: (1) $Fe + H_2O \rightarrow Fe(OH^-)_{ads} + H^+$; (2) $Fe(OH^-)_{ads} \rightarrow Fe(OH)_{ads} + e^-$; (3) $Fe(OH)_{ads} + H_2O \rightarrow FeOOH + OH^-$; (4) $Fe(OH)_{ads} + SO_4^{2-} \rightarrow FeSO_4 + OH^- + e^-$; and (5) $FeSO_4 + 2H_2O \rightarrow FeOOH + SO_4^{2-} + 3H^+ + e^-$. Reaction (3) is assumed to be slow; (4) and (5) are rapid. The SO_4^{2-} is assumed to be formed by the rust-catalyzed oxidation of sulfur dioxide. It is assumed that steps (4) and (5) are the primary corrosion processes above some limiting value of SO_4^{2-} activity.

12. Mechanism of Atmospheric Rusting. U. R. Evans and C. A. J. Taylor. Corros. Sci., v. 12, No. 3, 1972, pp. 227-246.

Corrosion research conducted at Cambridge and pertaining to the connection between the electrochemical mechanism of atmospheric corrosion and that of corrosion under immersed conditions is reported. Iron and steel samples were used. The results indicate the major role of the electrochemical cycle mechanism on the corrosion of iron in atmospheres containing large amounts of sulfur dioxide.

13. Mechanisms of Atmospheric Corrosion. A. Bukowiecki. Oberflaeche-Surface, v. 13, No. 9, 1972, pp. 219-226 (German).

The results and conclusions of several extensive steel corrosion studies made by the author and others are summarized and reviewed. Particular emphasis is given to the concept of critical humidity in connection with the corrosive action of solid salts and the cause of

pinhole corrosion. The effect of acids and sulfur dioxide is also considered.

14. Mechanism of Rusting Under Different Conditions. U. R. Evans. Brit. Corros. J., v. 7, 1972, p. 10.

Rust formed from iron immersed in a salt solution is a secondary product precipitated where the soluble anodic and cathodic products meet. Being mainly produced at a distance from the metallic surface, it cannot protect, and the corrosion proceeds at a nearly uniform rate. Only if either anodic or cathodic product is sparingly soluble will corrosion be slowed down--the two cases being known as anodic and cathodic inhibition. The currents passing between anodic and cathodic areas have been measured and are found to correspond to the corrosion rate in the sense of Faraday's law. During corrosion by drops of salt solution placed on a horizontal surface, the current passing between the central anode and the peripheral cathode has been shown up by a magnetic method due to Blaha. In these cases the electrochemical mechanism is not in doubt. Atmospheric corrosion set up by saline dust particles can be explained by a mechanism like that of drop corrosion. That set up by moist air containing sulphur dioxide is found to be connected with the formation of ferrous sulphate; when once this has been produced, the presence of sulphur dioxide in the gas phase is not needed for the continuation of rusting. Here again there is evidence of an electrochemical mechanism. The anodic reaction is $\text{Fe} = \text{Fe(II)} + 2\text{e}$, whilst the cathodic reaction is the reduction of FeOOH to Fe_3O_4 , which is then oxidized by air to give a larger quantity of FeOOH than previously existed. Since the fresh rust formed at a sensible distance from the site of anodic attack, the rust, although adherent, is not protective. This action will continue only if an electrochemical conducting limb (FeSO_4 solution) and an electronically conducting limb (Fe_3O_4) are provided. If the humidity is so low that the FeSO_4 solution dries up, rust-formation by this mechanism will cease, explaining the principle of critical humidity as developed by Vernon and Bukowiecki. If the metal does not form an electronically conducting intermediate oxide, a mechanism providing rapid atmospheric attack will be impossible; this explains why zinc, which under immersed conditions is corroded more quickly than iron, suffers atmospheric attack more slowly. Indeed, a zinc coating is commonly used to protect iron under atmospheric condition.

15. Protective Rust Layer Formed on Low-Alloy Steels in Atmospheric Conditions. H. Okada, Y. Hosoi, K. Yukawa and H. Naito. Proc. 4th Int. Congr. Metal. Corros. (1969), National Association of Corrosion Engineers, Houston, TX, 1972, pp. 392-398.

The corrosion resistance to weathering of steels containing alloying elements such as Cu, Ni, Cr, and P may be due to the formation of a dense optically isotropic layer of amorphous spinel-type Fe oxide with an outer compact layer of optically active FeOOH . An anodic reaction is prevented by masking of active sites by the oxide layer, preventing penetration of H_2O and O_2 to the steel surface. A cathodic reaction may be prevented by the compactness of the outer FeOOH layer. In carbon steels, the optically active FeOOH layer is partially mixed with the optically isotropic layer

adjacent to the steel surface. This may permit crystallization of F_3O_4 , causing cracks in the layer and permitting penetration of O_2 and H_2O , and formation of additional $FeOOH$ at the surface.

16. Reactions of Sulfur Dioxide With Adsorbed Layers of Moisture Under Conditions of Atmospheric Corrosion of Metals. P. V. Strekalov, Y. N. Mikhailovskii. Zashch. Metal., v. 8, No. 5, 1972, pp. 573-576 (Russian).

A large number of researches have been devoted to the investigation of the effect of sulfur dioxide on the development of the corrosion process. It has been found that for the series of technically important metals such as iron, zinc, and others, there is a proportional relationship between sulfur dioxide content of the air and atmospheric corrosion. The variation in the kinetics of the corrosion process in the presence of sulfur dioxide gas is associated with oxidation of the sulfur dioxide at the metal surface to SO_3 , acidification of the moisture film, and the depolarizing function of sulfur dioxide. However, the fact that the corrosion rate of metals is independent of the sulfur dioxide concentration in an atmosphere with humidity below the critical value has so far not received a sufficiently rigorous physicochemical interpretation. In the present work, we have investigated the adsorption of sulfur dioxide from the gas phase on metals carrying adsorbed layers of moisture with various thicknesses, and we have also investigated the effect of adsorbed sulfur dioxide on the electrophysical and corrosion characteristics of zinc in a moist atmosphere.

17. Stress-Corrosion Susceptibility of Highway Bridge Construction Steels. C. S. Carter, M. V. Hyatt and J. E. Cotton. NTIS Report PB-222453/3, April 1972, pp. 301.

A catalog of steels used in highway bridge construction has been developed. A state-of-the-art survey on the stress-corrosion susceptibility of these steels has been conducted. The types and concentrations of corrosives that can be experienced in the highway environment have been established. It is concluded that carbon steels (A7, A9, A36, and A373), which have been used predominantly in bridge construction, are not susceptible to stress-corrosion cracking in the highway environment. Insufficient information is available to assess the stress-corrosion resistance of higher strength steels with the required level of confidence. Fracture mechanics type tests are proposed to obtain this information.

18. Survey on the Metal Corrosion by Air Pollution: Effect of Glauber's Salt on Metals. T. Nagano, A. Hattori, T. Nagai, Y. Ukishima, Y. Nakai and I. Iwasaki. Shizuoka-ken Eisei Kenkyusho Nenpo, No. 16, 1972, pp. 217-226 (Japanese).

Iron, aluminum, copper, zinc, and silver plates of given sizes were fixed to a support and exposed to sulfate at 6 locations at Yoshihara of Toyama City where pollution by sodium sulfate was significant. Sulfur

dioxide concentrations were measured by the lead peroxide candle method while particulate concentrations were measured by the deposit cage method. The metal plates were weighed before and after the exposures. The average sulfur dioxide concentrations from July 1971 to May 1972 ranged from 0.867 mg SO₃/100 square cm/day at Kashiwara-Arada to 1.202 mg SO₃/100 square cm/day at the Fujima T-House. The sodium sulfate concentrations in the air were estimated at 4.29 square km/month at Kashiwara-Arada. The iron plates showed considerable weight decreases at all the locations. A correlation coefficient (R) of 0.997 was obtained between the weight decrease of iron and the estimated Na₂SO₄ concentration in the air. Silver plates showed black-blue spots after exposure.

19. The Care of Old Buildings Today. D. Insall. The Architectural Press, London, 1972, 197 pp.

The causes of deterioration of lead, masonry, iron, tile, copper, wood, thatched roofs, and paintings in old buildings are discussed. Some of the causes are rain, atmospheric pollution, corrosion, dry rot, condensation, pests, wind, fungi, etc. Methods of restoration and preventative measures that can be taken are discussed.

20. The Effect of Copper (II) on the Crystallization of α -FeOOH. K. Inouye, S. Ishii, K. Kaneko and T. Ishikawa. Z. Anorg. Allg. Chem., v. 391, 1972, pp. 86-96.

Various α -FeOOH samples have been prepared with or without addition of Cu(II) (0-5% Cu/Fe) and examined by X-ray diffraction. BET surface area determination, electron-microscopical observation and DTA measurements were made. Doping with Cu in suitable amount impedes completely the formation of α -FeOOH. The mechanism of growth, based on the changes of particle size and crystallite dimension, appears to be different between pure and Cu-doped α -FeOOH. The reason of the remarkable effect of Cu on the crystallization process of α -FeOOH is discussed. The effect of Cu is likely relevant to the role of Cu added to anticorrosive steel used in the atmospheric environment.

21. The Effect of Magnetite on Atmospheric Rusting and Underrusting of Paint Coats. H. Schwartz. Werkst. Korros., v. 23, No. 8, 1972, pp. 648-663 (German).

The corrosion products formed in the atmospheric rusting of steel can be converted into magnetite under suitable conditions. Preferably, this conversion occurred at the FeSO₄ nests at which FeOOH was reduced by metallic iron, increasing considerably the ultimate rusting rate even below paints. The conversion behavior of natural rust offered an evaluation of the ultimate rusting susceptibility of a rusted surface. Rust formed in the atmosphere under natural conditions was stored several weeks under oxygen-free nitrogen at 97 percent relative humidity and the amount magnetite formed determined. This amount could increase to more than 90 percent with increase of the ultimate rusting rate to multiples of the original value. An oxygen concentration of less than 1 vol-pct was

sufficient to maintain a high corrosion rate. This method made possible a better characterization of the substrate layer than the characterizations by age, layer thickness, and rust origin.

22. The Influence of the Relative Humidity and Corrosion Products on the Adsorption of Sulfur Dioxide on Metal Surfaces. T. Sydberger and N. G. Vannerberg. *Corros. Sci.*, v. 12, No. 10, 1972, pp. 775-784.

The adsorption of sulfur dioxide on metal surfaces has been followed using an S-35 isotope. Experiments have been performed with 1.0×10^{-5} percent SO_2 (0.10 ppm) at relative humidities between 50 and 98 percent. The adsorption properties of polished iron, zinc, copper, and aluminum samples have been compared with those of pre-exposed samples of these metals. Measurements have shown a pronounced dependence of the adsorption rate on the humidity. Almost quantitative adsorption of sulfur dioxide has been obtained on pre-exposed iron samples at relative humidities of more than 80 percent. Remarkably low adsorption capacities at relative humidities of less than 90 percent have been found for the corrosion products of copper and aluminum. Changes in the adsorption rate with time have been used to study the corrosion initiation on polished iron surfaces.

23. The Structural Transformation of Ferric Oxyhydroxides and Their Activity Towards Sulfur Dioxide. T. Ishikawa and K. Inouye. *Bull. Chem. Soc. Japan*, v. 45, No. 8, 1972, pp. 2350-2354.

The structural transformation of ferric oxyhydroxides and their activity towards sulfur dioxide were studied by thermogravimetric analysis and X-ray diffraction in order to clarify the mechanism of acceleration of iron corrosion by sulfur dioxide in stack gas and in the atmosphere.

24. Various Factors Affecting Atmospheric Corrosion of Steels. J. Satake and T. Moroishi. *Proc. 5th Intern. Congr. on Metallic Corrosion* (Tokyo, Japan, May 1972), published by National Association of Corrosion Engineers, 1972, pp. 744-749.

Corrosion tests were conducted at various sites on carbon and low alloy steels for exposure periods up to 5 years. The corrosion rate data is correlated with the SO_2 , Cl^- content of the air and with rainfall. The tested samples contained more sulfur in the rust film than was in the metal. However, rain was the only atmospheric constituent that correlated well with corrosion in the latter stages of the test.

1971

1. Accelerated Atmospheric Corrosion Tests in Polluted Air. Influence of Dewing on Mild Steel in Sulfur Dioxide Environment. S. Yamasaki and Y. Yokoi. *Corrosion Engineering*, v. 20, No. 11/12, 1971, pp. 509-515.

The influence of the quantity of dewing and interval of dew cycle on the corrosion of mild steel panel exposed in an atmosphere of 20 ppm SO₂, 95-100 percent relative humidity was investigated and evaluated from the viewpoint of similarity to field tests, acceleration of test, and reproducibility of test results. The grade of dewing was classified into critical dewing (temperature difference (TD) between specimen and atmosphere = 0), light dewing (TD = 2°C), and heavy dewing (TD = 5°C). Dewing period (min)/drying period (min) cycles of 15/15, 30/30, 60/60, and 120/120 were selected, besides continuous dewing, for the test period of 24 hours. In heavy dewing, the shortest cycle of 15/15 showed the largest amount of corrosion, but the similarity to the corrosion pattern of field tests was weak. The reproducibility under the condition of the cyclic heavy and light dewing was very good, while that in the cyclic critical dewing was unstable. Continuous dewing under all but critical conditions has the tendency to reduce acceleration and similarity. To satisfy similarity, acceleration and reproducibility in the laboratory test, the condition of light dewing and comparatively rapid dew cycle, such as 30/30, was recognized to be optimum.

2. Air Pollution by Sulfur Oxides. Staff Report. National Industrial Pollution Control Council, Washington, D.C., Feb. 1971, 27 pp.

The report briefly discusses sulfur oxide air pollution. It mentions the sources of sulfur oxides; the characteristics of sulfur pollutants; the measurement of atmospheric sulfur oxides; the effects of atmospheric sulfur oxides on paints, metals, building materials, vegetation, and man and animals; the combined effects of sulfur oxides and particulate matter; epidemiological appraisal of sulfur oxides; the methods to reduce sulfur oxide pollution; and what industry and government are doing to attack the problem.

3. An Investigation of the Anodic Behavior of Low Alloy Steels. G. Bombara and G. Agabio. Corrosion, v. 27, No. 1, January 1971, pp. 26-30.

The anodic behavior of three low alloy steels and one mild steel was evaluated by potentiodynamic polarization measurements in bicarbonate, sulfate, and bisulfate solutions. Some significant features differentiated the steels as to their corrosion behavior in these media. These features were dependent on the alloying elements and were related to the practical performance of the steels in atmospheric corrosion tests. The effect of weathering on the anodic behavior of these materials in sulfate solution was evaluated by the use of polarization measurements on specimens artificially weathered by prolonged anodizing treatments at very low current densities.

4. Atmospheric Corrosion of Galvanized Steel. K. B. Barton. Proc. 9th Int. Conf. Hot Dip Galvanizing (1970), Ind. Newspapers Ltd., London, 1971, pp. 199-206.**

Corrosion of iron and zinc surfaces was compared. Two critical factors for iron are humidity and accelerators such as chloride and SO₂,

the latter being effective in very small concentrations. The accelerators accumulate in the corrosion products at the iron-rust boundary. For zinc, the corrosion mechanism is passive even in the presence of SO_2 , the control taking place at the outer corrosion product/atmospheric boundary. In an industrial atmosphere, 2 percent SO_4 was present in the corrosion products of iron, 15 percent in those of zinc. The effect of temperature on the atmospheric corrosion of iron is exponential; that of zinc linear. The dependence of corrosion rates of iron and zinc by active amounts of SO_2 was charted; the relation is valid only when a minimum concentration is exceeded. A distinction was made among the 3 periods in the life of a hot-dipped galvanized product exposed to atmospheric attack: a short time when the protective layer is formed from the corrosion products; a long period of corrosion that is directly proportional to the zinc-layer thickness and indirectly proportional to the aggressiveness of the atmosphere; and finally the period after most of the zinc coating has been consumed. Long-term atmospheric corrosion varies linearly with time. The zinc corrosion rate during wetting periods is a function of the total amount of accelerator falling on the surface.

5. Atmospheric Corrosion of Metals. M. Arpaia. Atti Not. Assoc. Ital. Metall., v. 26, 1971, pp. 363-367 (Italian).

A survey covers the corrosion effects of sulfur dioxide, sulfur trioxide, particulate ammonium sulfate, and hydrogen sulfide on iron alloys, copper, nickel, aluminum, zinc, and silver.

6. Atmospheric Tests. S. K. Coburn. Chapt. 17 in Handbook on Corrosion Testing and Evaluation, edited by W. H. Ailor, Electrochemical Society, Corrosion Monograph Series, J. Wiley, New York, N.Y., 1971, pp. 475-505.

The chapter traces the history of atmospheric corrosion testing and discusses the factors affecting atmospheric corrosion. Corrosion data for mild steel, stainless steel, zinc, copper, and aluminum are reported for various exposure sites from around the world.

7. Behavior of Rusted (Mild steel) Surfaces in Sulfur Dioxide Atmosphere. G. K. Singhanian, B. Lal and B. Sanyal. Labdev. Part A, v. 9, No. 3 & 4, 1971, pp. 223-225.**

The presence of rust on mild steel increases its susceptibility to further corrosion by adsorption of SO_2 under conditions of low temperature and low humidity that are not favorable for corrosion of freshly prepared samples. Rust films behave differently depending on their nature. When the film is very thin, it absorbs moisture and results in more corrosion, but when it becomes compact and nonporous on long exposure, it acts as a protective film.

8. Breakdown of Passivity in Low-Alloy Steels. L. Giuliani, G. Agabio and G. Bombara. Corrosion Science, v. 11, 1971, pp. 403-410.

Low-alloy steels can be protected in SO_4 solutions through precipitation of corrosion products. Periodic breakdowns of such a "coverage passivity" results in current blips, whose shape and frequency are highly specific of the type of steel. The qualitative classification which can be drawn from this phenomenon appears to correlate quite well with the corrosion resistance of steel as determined by atmospheric exposure tests.

9. Corrosion Induced by SO_2 Under Controlled Conditions. B. O. Heimler, T. Sydberger and N. G. Vannerberg. Chapt. 27 in Proc. 6th Scandinavian Corrosion Congr. (Gothenburg, May 24-27, 1971), 1971, 13 pp.

Metal samples have been exposed to humid atmospheres containing sulfur dioxide under controlled conditions. The surface structure of the samples has been studied with a scanning electron microscope and an electron microprobe. The increase in weight, the amount of sulphate formed and the adsorption of sulfur dioxide has been determined, the last using the radioactive sulfur isotope S-35. The phase composition of the corrosion products has been determined by X-ray diffraction and thermogravimetric analysis.

10. Corrosion of Metals by Sulfur Dioxide. G. K. Singhanian, B. Lal and B. Sanyal. Labdev. Part A, v. 9, No. 3 & 4, 1971, pp. 214-216.

Concentration and aeration influence the corrosion of metals in aqueous solutions containing $< 4.0 \text{ g SO}_2/100 \text{ cm}^3$. Mild steel and Zn are heavily attacked, while there is slight attack on Al and none on Cu. Maximum corrosion was observed in mild steel at 40° at an intermediate SO_2 concentration.

11. Corrosion of Some Steels Under the Atmospheric Conditions of a Damp Subtropical Sea Climate. F. N. Tavazde, S. N. Mandzhgaladze, V. S. Kemkhadze, T. Dashniani and G. K. Dzinchharadze. Prot. Steel Struct. Atmos. Corros., 57th Proc. Event Eur. Fed. Corros. (1970), v. 1, 1971, pp. 71-83 (German).

The climate of Batum (Georgia, USSR) was found to exert no particular effect on the corrosion of stainless steels. Steels 1Kh18N9T and Kh15AT15 were found to be extremely corrosion resistant. Materials in NaCl solutions are tabulated and discussed.

12. Effects of Atmospheric Pollutants on the Corrosion Behavior of Steels. F. H. Haynie and J. B. Upham. Mater. Prot. Performance, v. 10, No. 11, November 1971, pp. 18-21.

The effects of atmospheric pollutants on the corrosion behavior of steels was studied experimentally for three types of steel selected on the basis of their known corrosion behavior by mounting 25 panels, each 16,000 μm thick, of each steel on exposure racks on porcelain insulators facing south and inclined 30° , at U.S. Public Health Service Continuous Air

Monitoring Project stations in Chicago, Cincinnati, New Orleans, Philadelphia, San Francisco, and Washington. These stations record concentrations of carbon monoxide, nitric oxide, nitrogen dioxide, sulfur dioxide, total hydrocarbons, and total oxidants (mainly ozone). Five replicates of each steel were removed after exposure periods of 4, 8, 16, 32, and 64 months. More than 90 percent of the variability in the corrosion behavior of the three types of steel could be accounted for by differences in concentration of two pollutants. Sulfur dioxide increased corrosion and oxidants decreased corrosion. Because these two effects are counteracting, the relative rates by which these pollutants are reduced in the future will strongly affect the corrosion behavior of steels.

13. Effect of Climatic Factors on Metal Corrosion Under Natural Conditions. G. B. Klark. Prot. Steel Struct. Atmos. Corros., 57th Proc. Event Eur. Fed. Corros. (1970), v. 1, 1971, pp. 214-229 (German).

Storage tests carried out on steels over 20 years have shown that in dry climates corrosion increases with the amount of alloyed metal. When stored uncovered, the rate of corrosion decreases after the first 2 years; when covered, the rate is constant for 10 years. Salt in the atmosphere enhances corrosion.

14. Effect of Environmental Factors on the Corrosion of Steels. F. J. Egan. Australasian Corrosion Eng., v. 15, No. 6, July 1971, pp. 9-16.**

The effect of environmental factors, including rain and atmospheric pollutants, on exposed steel are examined. The amount of moisture and sea air are a function of geographical location, but rain, humidity, and sea salts cause rusting and speed corrosion. Dusts, e.g., carbon smoke, sulfurous gases, and ammonium salts are additional factors in steel corrosion. Pollutants dissolved in rainwater increase the pH value and aggravate corrosive effects. Corrosion will be more severe in an atmosphere continually saturated with water and containing carbon particles, chlorides, and sulfates. The effect of alloying steel on corrosion resistance is discussed.

15. Laboratory Studies of Atmospheric Corrosion. K. Bohnenkamp. Prot. Steel Struct. Atmos. Corros., 57th Proc. Event Eur. Fed. Corros. (1970), v. 1, 1971, pp. 84-97 (German).

Atmospheric corrosion under laboratory conditions is studied by differential measurement of the pressure of the consumed oxygen at a sensitivity of 0.1 g/m^2 . The effect of single and repeated addition of SO_2 on the rate of rusting is studied.

16. Magnetite in Rust as a Corrosion Stimulator. H. Schwartz. Prot. Steel Struct. Atmos. Corros., 57th Proc. Event Eur. Fed. Corros. (1970), v. 1, 1971, pp. 13-56 (German).

The changing of rust into magnetite (Fe_3O_4) and its stimulating effect on corrosion was investigated. Three types of rust produced by exposing prepared ferrous test panels in industrial atmospheres for fixed periods of time were examined. Magnetite strongly promoted corrosion. On panels exposed in the Ruhr for 1 year the rusting rate increased from approximately 650 $\mu\text{m}/\text{yr}$ to approximately 1,050 $\mu\text{m}/\text{yr}$ when the magnetite content increased from 6 to 31 percent. On panels exposed in Stuttgart for 10 weeks the initial rusting rate of approximately 330 $\mu\text{m}/\text{yr}$ increased to approximately 930 $\mu\text{m}/\text{yr}$ when magnetite content increased from 0 to 97 percent. On panels exposed in Stuttgart for 1 year the rate went from approximately 70 $\mu\text{m}/\text{yr}$ to approximately 390 $\mu\text{m}/\text{yr}$ when the magnetite content went from 0 to 29 percent. The listed corrosion activities are the rusting rates at 97 percent relative humidity without the addition of corrosion promoters. The values were obtained by measuring the oxygen consumption. The magnetite content is based on total oxides determined by X-ray analysis.

17. Metal Coatings on Steel at Lighthouse Beach, Lagos. J. F. Stanners. Brit. Corrosion J., v. 6, No. 5, September 1971, pp. 211-215.

Fifty to eighty μm coatings of Zn, Pb, and Al were applied to plates of hot-rolled mild steel and were exposed for 8.7 yr at angles of 45° facing the sea at Lighthouse Beach, Lagos. Daily temperatures were 21-32°C, relative humidity more than 85 percent, and annual rainfall was approximately 1,800 mm (mainly between March and October). Sprayed aluminum and electrodeposited zinc coatings prevented corrosion. Hot-dipped zinc coatings were quite successful, but sprayed zinc and electrodeposited lead coatings were unsatisfactory.

The methods of applying the coatings and the breakdown of the coatings during the test are described.

18. On The Protective Nature of Atmospheric Rust on Low-Alloy Steel. I. Matsushima and T. Ueno. Corros. Sci., v. 11, No. 3, 1971, pp. 129-140.

Experiments on carbon and low-alloy weathering steels exposed to the industrial atmospheres of Kawasaki, Japan, showed that the ability of rust to convert sulfur dioxide to trioxide, and thus the rate of sulfate formation depends on the steel composition. It is lower for the more corrosion-resistant steels. The corrosion rates depend on the number of macroscopic anodic sites, (detected by autoradiography) on the rusted surfaces.

19. Present Status and Prospects on Air Pollution. U. Bardelli. Ingegneria, v. 5, 1971, pp. 311-316. (Italian)

This survey covers the effects of air pollutants such as carbon dioxide, sulfur dioxide, hydrogen sulfide, ozone, hydrogen chloride, and nitrogen oxides on various materials, e.g., metals, paints, cloth, leather, paper, and rubber; and the use of protective wax, paraffin, and bitumen films.

20. Role of Sulfur Dioxide in Atmospheric Corrosion. D. J. Spedding. Chem. Ind. N.Z., v. 6, 1971, pp. 39-41.

The effect of sulfur dioxide on the atmospheric deterioration of metals, building stone, book paper, and leather is reviewed.

21. State of the Art and Aspects of Surface and Corrosion Protection Technology. Part 1. W. Burkhardt. Technik (Berlin), v. 26, No. 11, November 1971, pp. 697-704.**

All corrosion is caused by the effect of the environment on metals, metal alloys, and metallic protective layers. Two stages can be distinguished in the process: chemical corrosion in dry, gaseous media wherein the primary reaction is between the metal and the oxygen of the air, other corrosive gases being hydrogen, sulfur dioxide, and chlorine; and the active electrochemical loosening of metal. The influencing factors of atmospheric corrosion are temperature and temperature changes; moisture and precipitation; solar radiation; cloudiness; wind; and the concentration in the atmosphere of oxygen, SO_2 , CO_2 , Cl , H_2S , NH_3 , soot, and dust. The corrosive attack is accelerated when the relative humidity rises above 70%. With relative humidities between 70 and 85% the type and concentration of pollution has an accelerating influence. The corrosion speed in microns/annum to the minus first power for iron is 5-60 in rural air, 30-70 in urban air, 40-160 in industrial air, and 60-230 in marine air; for lead, it is 0.7-1.4 in rural air, 1.3-2.0 in urban air, and 1.8-3.7 in industrial air.

22. Steels Fit for the Countryside. G. Smith. New Scientist, v. 52, No. 775, December 23, 1971 pp. 211-213.

Low-alloy "weathering steels" don't rust in the ordinary way, but form a tough protective coating ranging in colour from a warm, dark reddish brown to a purple grey. Requiring little maintenance, they are bound to rival the use of prestressed concrete, aluminum alloys, and conventional steels in the construction industry.

23. Study of the Rust Structure of Low-Alloy Steel. R. Engelhardt, U. Rasemann, H. Baum, H. Boudroit and E. Kunze. Neue Huette, v. 16, No. 9/10, Sept.-Oct. 1971, pp. 593-597. (German)

Low-alloy steel samples were exposed to an atmosphere with varying relative humidity. Sulfur dioxide was added discontinuously. Three steel types were examined. The exposure of the samples at 76% relative humidity caused no changes of the diffraction pattern. Corrosion resistant low-alloy steel, Corten steel, and a comparative non alloyed steel sample were exposed to the open atmosphere. Examinations of the rust layer after 6, 12, and 18 months revealed a direct influence of the climatic conditions as well as of the steel composition. The thickness of the rust fluctuated between 5 and 7 micron. Salt depositions were found both on the corrosion resistant low-alloy steel as well as on the nonalloyed steel. They were identified as iron sulfate. The quantity found on the

steel sample was in relation to the SO_2 content of the atmosphere. A 20 to 40% enrichment of sulfur was found in the rust with respect to the atmospheric SO_2 concentration.

24. Sulfates in Rust Formed During Atmospheric Corrosion of Iron. J. Honzak. Prot. Steel Struct. Atmos. Corros., 57th Proc. Event Eur. Fed. Corros. (1970), v. 1, 1971, pp. 98-110 (German).

An investigation was made of the properties and composition of rust layers formed during atmospheric corrosion of iron. The test samples were exposed in typical industrial, urban, and rural atmospheres. The rust layers were divided in three sublayers: (1) removed by brushing, (2) freed by bending the brushed sample, and (3) dissolved by pickling. Iron (II) and iron (III), the amount of anions, moisture content, and sulfate content were determined. Different conditions at the test sites led to rusts of different sublayer compositions. In a model experiment, the SO_4^{2-} could not affect the corrosion reaction kinetics.

25. Technical-Economic Evaluation of Air-Pollution Corrosion Costs on Metals in the U.S. F. W. Fink, F. H. Buttner and W. K. Boyd. NTIS Report PB-198453, February 19, 1971, 160 pp.

A study has been conducted to provide an estimate of the cost to the nation's economy resulting from the corrosion damage to metals by exposure to polluted air. More specifically, the major objectives may be stated as follows: Assess the total economic loss to the nation in dollars resulting from the increased corrosion damage of externally exposed structures or systems caused by the presence of man-made pollutants in the atmosphere. Establish from predicted changes in population, industrial activity, technology of pollution control, corrosion prevention, external structures, and air pollution regulations the probable size of this economic loss in 1980.

26. The Mechanism of Atmospheric Rusting and the Effect of Cu and P on the Rust Formation of Low Alloy Steels. T. Misawa, T. Kyuno, W. Suetaka and S. Shimodaira. Corrosion Sci., v. 11, No. 1, January 1971, pp. 35-48.

The oxidation processes of Fe(II) hydroxo-complexes to α -, β -, γ -, and δ -FeOOH and Fe_3O_4 , which are important atmospheric products of steels, and the effect of Cu^{2+} and PO_4^{3-} ions on the oxidation of the Fe(II) hydroxo-complexes in aqueous solutions have been investigated. The mechanism of atmospheric rusting deduced from the results obtained in the present investigation has been used to explain the difference in behavior between ordinary mild steels and low alloy steels during atmospheric exposure. It is concluded that Fe(II) complexes are transformed to amorphous δ -FeOOH by the catalytic effect of copper and phosphorus present in steels. The amorphous δ -FeOOH forms a compact rust layer that enhances corrosion resistance of the steel.

27. The Spreading of Sulphate Nests on Steel in Atmospheric Corrosion. K. Barton, D. Kuchynka, Z. Bartonova and E. Beranek. Corrosion Science, v. 11, 1971, pp. 937-942.

Radiochemical and microscopical investigations of the behavior of sulphate nests in the course of atmospheric corrosion as well as dissolution characteristics of sulphate from nests containing rusted steel leads to a description of the spreading of sulphate nests as a discontinuous process. Periodic cracking of a membrane surrounding the nest causes concentrated FeSO_4 solution or solid crystal to be expelled and results in the formation of new corrosion centers. The mechanism of this process is explained with the assumption of anion permeability of the membrane.

28. Use of Weather-Resistant RBH 35 Steel for Construction. W. Witte. Prot. Steel Struct. Atmos. Corros., 57th Proc. Event Eur. Fed. Corros. (1970), v. 1, 1971, pp. 176-186 (German).

A description of the mechanical properties and resistance to atmospheric corrosion of steel RHB 35 is given.

29. Weather-Resistant Structural Steels. Corrosion Behavior. F. Wallner, H. Demmel, F. M. Oberhauser and J. Brandstaetter. Prot. Steel Struct. Atmos. Corros., 57th Proc. Event Eur. Fed. Corros. (1970), G. V. Akimov Nat. Res. Inst. Prot. Mater., Prague, Czech., v. 1, 1971, pp. 230-244.

A review is presented on the physical-chemical and kinetic basis of steel corrosion and the influence of the steel components on corrosion. Corrosion resistance is ascribed to the formation of protective covering layers.

1970

1. Accelerated Atmospheric Corrosion Tests in Polluted Air. Mild Steel and Aluminum in Sulfur Dioxide Environment. S. Yamasaki and Y. Yokoi. Boshoku Gijutsu, v. 19, 1970, pp. 335-339 (Japanese).

One thousand liter/hr humid air, contaminated with 40 ppm SO_2 , was continuously fed to a test chamber (about 115 liter capacity) by Yamasaki's Constant Volume Gas Pumps. The relation of stationary concentration of SO_2 gas in the chambers and corrosion rate with the number of specimens of mild steel and aluminum plate respectively were obtained under the conditions of dew-cycle (25-50°C/60-60 min) and constant temperature (30°C and 50°C). The corrosion rate in the dew-cycle test was higher than that in the constant temperature test at the maximum temperature in the dew-cycle test. The decrease of stationary SO_2 concentration in tests with specimens corresponded to the increase in the corrosion rate. It is important for the reproducibility of an accelerated test to provide not only the concentration, but the flow rate of the

contaminated air and the total surface area of the specimens to be tested.

2. An Isotopic Tracer Method For Studying the Mode of Reaction of Sulfur Dioxide on Metal Surfaces. N. G. Vannerberg and T. Sydberger. *Acta Chem. Scand.*, v. 24, No. 3, 1970, pp. 1084-1085.

An apparatus has been designed to study the corrosion initiation of relatively low concentrations (0.1-1.0 ppm) of sulphur dioxide at room temperature. In order to be able to analyze the corrosion products quantitatively, a ^{35}S -labelled sulphur dioxide has been used. Preliminary measurements indicate a high percentage of sulphate in the corrosion products.

3. Atmospheric Corrosion of Fe-Cu Alloys and Cu-Containing Steels. D. Fyfe, C. E. A. Shanahan and L. L. Shreir. *Corrosion Science*, v. 10, No. 11, November 1970, pp. 817-830.

Exposure tests in rural, marine, and industrial environments have shown that the effect of Cu is small in S-free alloys, but a marked decrease in the corrosion rate is observed when the alloy contains S. These results have been explained by assuming that the Cu dissolved from the alloy reacts with S^{2-} and HS^- , which are known to stimulate the corrosion of Fe, with the formation of insoluble Cu sulfides. Thus the deleterious action of the sulfide ions, which may be formed from sulfides in the alloy or from atmospheric pollutants, is nullified with a consequent decrease in the corrosion rate. The mechanism proposed, which has been developed from studies of pure Fe alloys, should be applicable to Cu-containing commercial steels, although the behavior of these two types of alloys has shown certain differences.

4. Atmospheric Pollution and Historic Buildings. A Contemporary Urban Problem. C. Berindan. *Centre Belged'Etude et de Documentation des Eaux (Tribune de)*, v. 23, No. 324, November 1970, pp. 498-503 (French).

Discussion of the factors that cause the deterioration of buildings. These factors can be natural (climatic conditions, catastrophes) or manmade (atmospheric pollution being the principal cause).

The effects of atmospheric pollution on construction materials are brought about by a mechanical action (the blackening and staining of facades, abrasion of finishes) and by a chemical action (primarily due to sulfur dioxide). The climatic conditions such as relative humidity and temperature favor certain deterioration reactions.

Solutions are proposed to fight the damage; to protect and restore buildings in polluted towns, that is, reduction of pollution emissions; to choose carefully sites for new pollution sources; to utilize extensive tree plantings in protective perimeters around the buildings; and to use protective coatings.

5. Corrosion Behavior of the Major Architectural and Structural Metals in Canadian Atmospheres. Summary of Ten-Year Results of Group I. E. V. Gibbons. Nat. Res. Counc. Can., Div. Bldg. Res., Tech. Paper No. 328, 1970, 21. pp.

The atmospheric corrosion behavior of metals in different Canadian atmospheres was studied. The concentration of SO_2 was closely related to the severity of corrosion. Of the metals tested, the 3 stainless steels had the best corrosion resistance, showing negligible corrosion at all sites except the roof of the Halifax Federal building. The aluminum alloys were next in corrosion resistance followed by rolled zinc. The 3 alloy steels and the magnesium alloys had the highest corrosion rates. The Halifax roof site was the most corrosive of the sites. York Redoubt, Montreal, and Trail were similar with respect to atmospheric corrosion performance. The Ottawa site was next in order of corrosivity followed by Saskatoon, Esquimalt, and Norman Wells. In general, the rate of corrosion decreased with time after the first year of exposure. With the exception of the rolled zinc and the magnesium alloys, the earthward sides of the specimens were more severely attacked than the skyward sites.

6. Corrosion of Building Materials. A. Valeriana de Seabra and M. Cravo. Tecnica (Lisbon), v. 32, 1970, pp. 493-512 (Portuguese).

The corrosion of reinforcing steel, Zn, Cu alloys, Al, etc. is reviewed.

7. Critical Humidity in the Atmospheric Corrosion of Steel. K. Barton and Z. Bartonova. Werkst. Korros., v. 21, No. 2, 1970, pp. 85-88 (German).

Clean and prerusted specimens of carbon steel were exposed to atmospheres of 21.5, 35, 60, 72.7, 87, 96, or 100 percent relative humidity at 25°C . The moisture present in the rust was lower than had been assumed so far. The sorption properties of the rust had an important bearing on the amount of H_2O present on the surface. The sorption capacity was improved with SO_4^{2-} ions. The amounts of electrolyte at 100 percent relative humidity were 4 and 10 g/m^2 at surfaces without and with SO_4^{2-} , respectively. For technical purposes the critical humidity should be 80 percent.

8. "Deposit Corrosion" of Stainless Steels in Aggressive Atmospheres. G. Agabio and A. Tamba. Brit. Corros. J., v. 5, No. 3, 1970, pp. 112-116. **

Laboratory techniques were examined to assess the effect of deposited matter simulating atmospheric dust deposits on the localized corrosion of stainless steels of A.I.S.I. types 302, 304, 316, 410, and 430. Environments included salt-spray cabinet and sulfur-contaminated atmospheric media with SO_2 , H_2S , etc.; deposits with and without NaCl were studied, along with carbon-black, activated carbon, granulated graphite, SiO_2 , etc. Potential measurements were included. Carbon deposits in the presence of NaCl produced pitting in times of 6-10 days; susceptibility

to this type of attack decreased in the order A.I.S.I. type 302 > 304 > 316. Potential measurements on dusted specimens under NaCl-spray indicated that the mechanism of pitting by carbon deposits was related to the catalytic action of this element on the cathodic reduction of oxygen; under SiO₂ no attack was observed in any test. H₂S produced severe localized corrosion even in the absence of Cl⁻ while SO₂ in the latter state produced no visible attack in up to 20 days. Corrosion potential measurements during salt-spray testing is a very promising technique for the rapid assessment of stainless corrosion in atmospheres.

9. Kinetics of Iron and Zinc Corrosion in a Humid Medium. A. M. Zinevich, E. I. Sergeeva, Y. N. Mikhailovskii and V. B. Serafimovich. Zashch. Metal, v. 6, No. 3, 1970, pp. 333-336 (Russian).**

Zinc and iron corrode in a humid atmosphere in a passive state. The protective properties of the passivating film are determined by the humidity of the atmosphere and the concentration of the activator in the air.

10. Properties of Electrolyte Films Formed Through Atmospheric Corrosion. D. Knotkova-Cermakova and J. Vlckova. Werkst. Korros., v. 21, No. 1, 1970, pp. 16-21 (German).**

The compositions of electrolyte films formed on glass as well as on Cu, Zn, and Fe in a 1, 28, or 55 ppm SO₂-containing atmosphere were investigated with fresh hard precorroded specimens. The SO₂ absorbed in the solution was very rapidly oxidized to SO₄²⁻ when corrosion products such as FeSO₄, CuSO₄, or FeCl₃ were dissolved in the electrolyte film. The pH value in the electrolyte did not vary as a function of the SO₂ partial pressure.

11. Reaction Between SO₂ and Wet Metal Surfaces. N. G. Vannerberg and T. Sydberger. Corrosion Science, v. 10, 1970, pp. 43-49.

The drastic corrosion of iron in an atmosphere containing sulfur dioxide has been shown to be due to the catalytic effect of iron oxides and hydroxides on the formation of H₂SO₄ from SO₂, H₂O, and O₂. Measurements performed on samples of iron and rust in an atmosphere containing water vapor, O₂ and SO₂ at 95°C indicate an almost quantitative oxidation of adsorbed SO₂ to H₂SO₄. The protons thus formed accelerate the corrosion attack on materials containing iron. The rate of production of protons from samples of copper and aluminum is low and these metals also show a relatively good resistance to sulfur dioxide. Despite a low proton production rate, however, samples of zinc are severely corroded in atmospheres containing sulfur dioxide, which indicates a corrosion mechanism differing from that proposed for iron.

12. Stimulation of Atmospheric Rusting by Sulfates. K. Barton and Z. Bartonova. Werkst. Korros., v. 21, No. 1, 1970, pp. 25-27 (German).**

Steel samples containing carbon 0.12, copper 0.06, phosphorus 0.007, and sulfur 0.02 percent were cleaned with inhibited HCl. Some of them were prerusted by HCl vapor and by storing at 95 percent relative humidity and room temperature for some months. Both materials were treated with FeSO_4 solutions, dried, and stored at 95 percent relative humidity. Weight measurements showed that the rate of corrosion initially decreased, following a first order law, and finally became constant. The initial stage was less pronounced for the prerusted samples. A critical SO_4^{2-} activity at the steel-rust interface is discussed above which the corrosion is accelerated.

13. Systems Analysis of the Effects of Air Pollution on Materials. R. L. Salmon. NTIS Report PB-209192, January 15, 1970, 196 pp.

The report describes research concerned with determining the economic effects of air pollution on materials. The research results constitute an important first step in providing economic justification for setting air pollution control standards and for implementing control regulations. The first three chapters of the report describe the methodology and approach used in conducting the research. The next three chapters present data on air pollutants and economically important materials. The following three chapters are concerned primarily with analysis of the data. The final chapter offers conclusions drawn as a result of the over-all research program, and identifies areas where further action is warranted.

14. The Importance of Air Pollution in the Corrosion of Stone and Metals. E. M. Winkler. Eng. Geol., v. 4, No. 4, 1970, pp. 327-334.

Evidence is presented that polluted air not only affects life but also stone, concrete, and metal as well. Carbon dioxide and the sulfates are the strongest corrodents. Less strong are the nitrates and chlorides.

15. The Role of Rust Layers on the Corrosion Process of Steels in the Atmosphere. H. Okada, Y. Hosoi and H. Naito. Tetsu-to-Hagane (J. Iron Steel Inst., Japan), v. 56, No. 2, 1970, pp. 277-284 (Japanese).

An electrochemical investigation was made to determine the role of rust in atmospheric corrosion. The cathodic reaction of the rusted steel consists mainly of the reduction of FeOOH (brown rust) to Fe_3O_4 rather than the reduction of dissolved O_2 , and the anodic reaction is the dissolution of iron. In low-alloy steels for atmospheric corrosion resistance, both anodic and cathodic reactions are suppressed by the formation of a protective rust layer after exposure to the atmosphere for more than 3 to 5 years. Anodic reaction is prevented by the masking of active sites on the steel surface by the formation of a dense amorphous iron oxide layer and the cathodic reaction is suppressed by the increasing difficulty in reducing FeOOH .

16. The "Rustless" Iron Pillar at Delhi. G. Wranglen. Corrosion Science, v. 10, 1970, pp. 761-770.

The 1,600-year old forge-welded wrought iron pillar at Delhi, India (approximate average composition: 0.15%C, 0.25%P, 0.005%S, 0.05%Si, 0.02%N, 0.05%Mn, 0.03%Cu, 0.05%Ni, balance Fe) still shows only slight signs of rusting above ground. While the composition of the material, particularly its low sulfur and high phosphorus contents, is conducive to a low corrosion rate in atmospheric environments, the deciding factor is the dry and unpolluted climate of the area, the large mass of the pillar being a contributory factor. The part of the pillar which is below ground is covered by a rust layer, about 1 cm thick, and shows deep pitting. Above ground, the pillar is coated by a protective oxide film, 50 to 500 μm thick, analyzed by Ghosh as: 67.0% Fe_2O_3 , 13.1%FeO, 14.8% H_2O , 1.7% PO_2 , 3.1% SiO_2 . Assuming a parabolic growth rate of the oxide film, its thickness is in accordance with the present-day corrosion rate of carbon steel at Delhi, determined by Hudson, and corresponding to the formation of an oxide film 5 μm thick in the first year.

17. The Weathering and Performance of Building Materials. J. W. Simpson and P. J. Horrobin, eds., Medical and Technical Publishing Co. Ltd., 1970, 277 pp.

The weathering and performance of concrete, clay products, timber, plastics, and metals such as aluminum, zinc, copper, lead, and steels is discussed.

18. Use of Environmental Data in Atmospheric Corrosion Studies. J. F. Stanners. Brit. Corros. J., v. 5, No. 3, 1970, pp. 117-121.

In considering the significance of meteorological and pollution data in atmospheric exposure trials on metals and alloys, a distinction is drawn between (a) empirical and (b) theoretical approaches. Under (a) aspects covered include variation of corrosion rate with atmospheric temperature, wet exposure time in place of total time, etc.; great significance is attached to corrosion effects after prolonged exposure times. Various empirical equations covering these parameters are suggested for corrosion exposures at Tokyo, Moscow, Sheffield, and Ottawa, for steel, copper, zinc, etc. Under (b) corrosion rates and mechanisms are discussed along with the interrelation between the rust film itself and the water uptake; time lags in establishing equilibrium under changing environmental conditions can be as significant as the equilibrium conditions themselves. Kinetics are influenced by many factors including cathode and anode area, their potential difference and distance apart, diffusion paths of cathodic and anodic polarizers and depolarizers, electrolyte resistance, etc.; cathodic control by O_2 depolarization appears to operate in wet conditions while H_2 evolution can play a part and SO_2 can also depolarize the cathode. Anodic passivation can be rate-controlling in the absence of Cl^- , at least when electrolyte films are thin. Measurement of environmental conditions are detailed.

19. Weather-Resistant Structural Steels. Corrosion Behavior. F. Wallner, H. Demmel, F. M. Oberhauser and J. Brandstaetter. Berg-Huettenmaenn. Monatsh., v. 115, No. 11, 1970, pp. 304-311 (German).

Weatherproofed structural steels are low-alloyed nonstainless steels. A review on rusting process by direct oxidation of Fe to FeO and by indirect oxidation by electrochemical process in the presence of water is given. Influence of alloying metals in steel is shown. Cr, Mo, Cu, and P decrease corrosion.

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1. Accelerating Effect of Sulfur Dioxide and Water on Atmospheric Corrosion of Rusty Iron. K. Barton and Z. Bartonova. Werkst. Korros., v. 20, No. 3, March 1969, pp. 216-221 (German).

Laboratory study shows that the dependence of corrosion rate on humidity, from a critical amount to nearly 100 percent, can be expressed by rising quadratic parabolic equation; finding that SO₂ concentration (1, 10, and 100 ppm) had no influence on corrosion kinetics is attributed to saturation of rust with SO₄ anions; on basis of results, a new theory of atmospheric corrosion for already rusty steel is proposed.

2. Air Pollution Aspects of Aldehydes. Q. R. Stahl. Litton Systems, Inc., Environmental Division, Bethesda, Md., NTIS-PB 188-081, 1969, 149 pp.

Effects of aldehydes on humans, animals, plants, and materials from aldehyde production sources are reported.

3. Air Pollution Aspects of Ammonia. S. Miner. Litton Systems, Inc., Environmental Division, Bethesda, Md., NTIS-PB 188-082, 1969, 51 pp.

Effect of ammonia on humans, animals, plants, and materials from ammonia production sources such as Haber-Bosch process, coke plants, oil refineries, metallurgical and ceramic plants are reported.

4. Air Pollution Aspects of Arsenic and Its Compounds. R. J. Sullivan. Litton Systems, Inc., Environmental Division, Bethesda, Md., NTIS-PB 188-071, 1969, 72 pp.

Effects of arsenic and its compound on humans, animals, plants, and materials are reported.

5. Air Pollution Aspects of Asbestos. R. J. Sullivan. Litton Systems, Inc., Environmental Division, Bethesda, Md., NTIS-PB 188-080, 1969, 105 pp.

Effects of asbestos on humans, animals, plants, and materials are reported.

6. Air Pollution Aspects of Barium and Its Compounds. S. Miner. Litton Systems, Inc., Environmental Division, Bethesda, Md., NTIS-PB, 188-083, 1969, 69 pp.

Effects on humans, animals, plants, and materials from the mining and milling of barite are reported.

7. Air Pollution Aspects of Beryllium and Its Compounds. N. L. Durocher. Litton Systems, Inc., Environmental Division, Bethesda, Md., NTIS-PB 188-078, 1969, 92 pp.

Effects of beryllium and beryllium compounds on humans, animals, plants, and materials from beryllium production sources are reported.

8. Air Pollution Aspects of Boron and Its Compounds. N. L. Durocher. Litton Systems, Inc., Environmental Division, Bethesda, Md., NTIS-PB 188-085, 1969, 55 pp.

Effects of boron and boron compounds on humans, animals, plants, and materials from boron production sources are reported.

9. Air Pollution Aspects of Cadmium and Its Compounds. Y. C. Athanassiadis. Litton Systems, Inc., Environmental Division, Bethesda, Md., NTIS-PB 188-086, 1969, 92 pp.

Effects of cadmium on humans, animals, plants and materials are reported.

10. Air Pollution Aspects of Chlorine Gas. Q. R. Stahl. Litton Systems, Inc., Environmental Division, Bethesda, Md., NTIS-PB 188-087, 1969, 90 pp.

Effects of chlorine gas on humans, animals, plants, and materials are reported.

11. Air Pollution Aspects of Chromium and Its Compounds. R. J. Sullivan. Litton Systems, Inc., Environmental Division, Bethesda, Md., NTIS-PB 188-075, 1969, 86 pp.

Effects of chromium and its compounds on humans, animals, plants, and materials are reported.

12. Air Pollution Aspects of Ethylene. Q. R. Stahl. Litton Systems, Inc., Environmental Division, Bethesda, Md., NTIS-PB 188-069, 1969, 65 pp.

Effects of ethylene on humans, animals, plants, and materials are reported.

13. Air Pollution Aspects of Hydrogen Sulfide. S. Miner. Litton Systems, Inc., Environmental Division, Bethesda, Md., NTIS-PB 188-068, 1969, 107 pp.

Effects of hydrogen sulfide on humans, animals, plants, and materials (paint and metals) from hydrogen sulfide production sources such as tanneries, iron and steel industries, etc, are reported.

14. Air Pollution Aspects of Iron and Its Compounds. R. J. Sullivan. Litton Systems, Inc., Environmental Division, Bethesda, Md., NTIS-PB 188-088, 1969, 106 pp.

Effects of iron and its compounds on humans, animals, plants, and materials are reported.

15. Air Pollution Aspects of Mercury and Its Compounds. Q. R. Stahl. Litton Systems, Inc., Environmental Division, Bethesda, Md., NTIS-PB 188-074, 1969, 108 pp.

Effects of mercury and its compounds on humans, animals, plants, and materials are reported.

16. Air Pollution Aspects of Nickel and Its Compounds. R. J. Sullivan. Litton Systems, Inc., Environmental Division, Bethesda, Md., NTIS-PB 188-070, 1969, 76 pp.

Effects of nickel and its compounds on humans, animals, plants, and materials are reported.

17. Air Pollution Aspects of Phosphorus and Its Compounds. Y. C. Athanassiadis. Litton Systems, Inc., Environmental Division, Bethesda, Md., NTIS-PB 188-073, 1969, 86 pp.

Effects of phosphorus and its compounds on humans, animals, plants, and materials are reported.

18. Air Pollution Aspects of Selenium and Its Compounds. Q. R. Stahl. Litton Systems, Inc., Environmental Division, Bethesda, Md., NTIS-PB 188-077, 1969, 88 pp.

Effects of selenium and its compounds on humans, animals, plants, and materials are reported.

19. Air Pollution Aspects of Vanadium and Its Compounds. Y. C. Athanassiadis. Litton Systems, Inc., Environmental Division, Bethesda, Md., NTIS-PB 188-093, 1969, 105 pp.

Effects of vanadium chloride on humans, plants, animals, and materials are reported.

20. Air Pollution Aspects of Zinc and Its Compounds. Y. C. Athanassiadis. Litton Systems, Inc., Environmental Division, Bethesda, Md., NTIS-PB 188-072, 1969, 90 pp.

Effects of zinc and its compounds on humans, animals, plants, and materials are reported.

21. Aluminum Corrosion at Urban and Industrial Locations. W. H. Ailor, Jr. Proc. American Soc. Civil Engr., Journal of the Structural Division, October 1969, pp. 2141-2160.

Originally, high-purity aluminum was the common form of the metal. Because of the relatively low strength of the pure aluminum, the material was used mostly for exterior sheets, caps, and castings where strength was not required.

With the coming of the automobile and airplane, alloys of aluminum were developed having high strength and hardness. These alloys, using copper and, later, zinc, had reduced corrosion resistance in industrial and marine environments but could be protected by a higher purity aluminum cladding which was anodic to the core alloy. Alloys containing manganese, magnesium, and silicon were also developed for architectural use.

The results reported herein are based on long-term studies being conducted by the Reynolds Metals Company, Metallurgical Research Division at a number of test stations. The locations examined here include Richmond, Virginia; Chicago, Illinois; Phoenix, Arizona; Manila, Philippine Islands; and Widnes, England. Results include data for removals at 1 yr, 2 yr, and 7 yr. Test alloys were the following: 1199-H14-99.99% purity aluminum; 3003-H14-aluminum-manganese alloy; 3004-H36-aluminum manganese alloy; Alclad 3003-H14-aluminum-manganese alloy clad with 7072 alloy; 5154-H34-aluminum-3-1/2% magnesium alloy; 6061-T6-aluminum-magnesium silicide alloy; and 6063-T5-aluminum magnesium silicide alloy (less copper than 6061). In addition to these aluminum alloys, panels of mild steel and pure zinc were tested for reference and comparison.

22. Atmospheric Corrosion of Metals. Part VI--Corrosion of Metals at Jodhpur. M. L. Prajapat, G. K. Singhania and B. Sanyal. Labdev J. Sci. Tech., v. 7-A, 1969, p. 34.

Corrosion rates of mild steel and nonferrous metals have been determined at Jodhpur representing semi-arid or subtropical type of climate. It is observed that mild steel specimens exposed during non-aggressive months show lower yearly corrosion rates than specimens exposed in more aggressive months. Statistical analysis shows that corrosion rate depends upon wind velocity and number of rainy days. The metals studied in the atmospheric conditions of Jodhpur could be arranged in the following order as regards their proneness to corrosion: mild steel > zinc > galvanized iron > copper > brass > aluminum.

23. Atmospheric Corrosion of Steel in Some Tropical Locations in India. K. S. Rajagopalan, P. L. Annamalai, M. Sundaram and C. Rajagopal. Proc. 3rd Intern. Congr. on Metallic Corrosion, Moscow (1966), Swets-Zeitlinger, Amsterdam, Holland, v. 4, 1969, pp. 532-541.

Results are presented of outdoor exposure tests carried out for five years with steel in marine (Mandapam Camp), industrial-marine (Madras), and rural (Karaikudi) atmospheres.

Good correlation has been obtained at Mandapam Camp between wind velocity and salinity as well as atmospheric salinity and corrosion rate. There is also good correspondence at Mandapam Camp between mean temperature and corrosion rate. No such relationship between SO₂ pollution and corrosion rate, nor temperature and corrosion rate has been observed at Madras (an industrial-marine site). Perhaps the saline pollution complicates the former. Increase in temperature is accompanied by decrease in corrosion rate at Karaikudi, showing that other factors overshadow the effect of temperature at this site. There is also no relationship between corrosion rate and rainfall in all the three sites. The months in which the average humidities are higher than 70 percent relative humidity do not give higher corrosion rates as expected. This lends support to the view that the determining factor is not the average humidity but the microclimate and moisture condensation at the location of the stands.

A very high corrosion rate (25 to 30 mils/year) is obtained at Mandapam Camp at the shore site. In comparison, the corrosion rate at the 30 m site at Madras is 6 to 7 mils/year and the corrosion rate at Karaikudi (48 km from the sea) is 0.3 to 0.4 mils/year. The corrosion is linear with time at the shore site at Mandapam Camp which indicates that rust formed at this site is not protective. The corrosion rate, as well as salinity, decrease sharply when the distance from the sea increases up to a few hundred meters. The yearly rate of corrosion varies with the month of exposure but no particular relationship between monthly rate of corrosion and month of exposure can be inferred. Specimens exposed in the vertical position give the highest corrosion rate.

24. Calculation of Moistening and Metallic Corrosion in Atmospheric Environment. A. L. Golubev and M. K. Kadyrov. Proc. 3rd Intern. Congr. on Metallic Corrosion, Moscow (1966), Swets-Zeitlinger, Amsterdam, Holland, v. 4, 1969, pp. 522-531.

The time during which the moisture film stays on the surface of metal has been ascertained by meteorological indications and a map of the duration of moistening of the surface in the Soviet Union has been made.

The influence has been shown of various factors--the duration of moistening of the surface, the thickness of the moisture film, the aggressiveness of the atmosphere, the films of corrosion products, and the temperature--on the development of the corrosion processes on basic metals. Maps of the Soviet Union have been plotted, dealing with the corrosion of iron, zinc, cadmium, copper, and aluminum for the atmosphere of a rural locality. It has been demonstrated that it is possible to calculate the magnitude of metallic corrosion for areas with a different degree of SO₂ and NaCl atmospheric pollution.

25. Corrosion in the Atmosphere. P. Atterby. NTIS Report N71-26259, November 1969, 9 pp. (Swedish)

The main principles of atmospheric corrosion are considered. Examined are: air pollution, exposure to atmosphere, metals and metal alloys, painting, car corrosion, temporary protection against corrosion and out-stations for atmospheric exposure. The report concludes with basic rules for sound common sense about corrosion.

26. Corrosion of Metals in the Tropics. B. Sanyal, G. K. Singhanian and J. N. Nanda. Proc. 3rd Inter. Congr. on Metallic Corrosion, Moscow (1966), Swets-Zeitlinger, Amsterdam, Holland, v. 4, 1969, pp. 542543.

Exposure of mild steel and some nonferrous metals have been made in India at a number of sites representing different climatic conditions to investigate their corrosion behavior. Meteorological data, including precipitation in the form of rain and dew, amounts of pollutants (for example, dust, sulphur dioxide and salinity) present in the atmosphere at each site, have been recorded. An attempt has been made to correlate the corrosion of metals with meteorological data by subjecting them to regression analysis. Corrosion rates could not be correlated to any single factor but a definite relation has been found between the rate of corrosion and the combined influence of a number of meteorological factors. The effect of dust, dew, and orientation of specimens has been investigated. A scheme has been drawn up for the classification of the country into various climatic zones from the corrosion point of view.

27. Corrosion of Steel. W. Schwenk. Stahl Eisen, v. 89, No. 10, 1969, pp. 535-547 (German).

An extensive literature review is given covering environmental corrosion of mild steel and low alloy steels, pitting, inter- and transcrystalline stress corrosion cracking of stainless steels and austenitic Mn steels, and corrosion at high temperatures. A short section on corrosion prevention is included. The discussion gives a comprehensive review of the corrosion of welds in chromium-nickel steels, with reference to heat treatment and γ -ferrite contents.

28. Effect of the Atmospheric Corrosion Products on Electrochemical Behaviour of Metals. G. B. Klark, G. K. Berukshtis and Z. I. Ignatova. Proc. 3rd Intern. Congr. on Metallic Corrosion, Moscow (1966), Swets-Zeitlinger, Amsterdam, Holland, v. 4, 1969, pp. 406-412.

The report sets forth the results of electrochemical investigations conducted on the specimens of zinc and steel after different periods of exposure in the open air and under a shed. The effect of the corrosion products upon the electrochemical characteristic of metals was estimated by the changes in the capacitance, resistance, cathodic and anodic polarization, and steady potential in time.

The mechanism of corrosion inhibition on zinc and steel is different. The corrosion rate of zinc drops sharply after the first wettings and remains nearly constant thereafter. Retardation of the corrosion rate of zinc is caused by the formation of thin layers of a hydroxide film possessing high insulating properties; the products of zinc corrosion take no part in the electrochemical process of corrosion. The curve of the steel corrosion rate versus time passes through a maximum. The increase in the corrosion rate after the first wettings is explained by the depolarizing properties of the products of corrosion of steel. The process of steel corrosion is retarded only after prolonged exposures in the open air; under a shed the rate of corrosion remains constant.

Investigations of the electrochemical properties of the corrosion products directly on metals provides a good explanation of the mechanism of metal corrosion under a layer of the corrosion products.

29. Effect of Chemical Composition on the Kinetics of Atmospheric Corrosion of Steel. P. Burda. *Werkst. Korros.*, v. 20, No. 12, 1969, pp. 999-1001 (German).

Atmospheric corrosion tests of 19 low-alloy steels (compositions given) were made in rural, city, and industrial locations. In general, phosphorus increased long-time atmospheric corrosion (there were exceptions to this with some steels in industrial atmospheres) while sulfate content usually partly offset this. Carbon and copper usually decreased long-time corrosion, but copper frequently increased short-time corrosion.

30. Evaluation of Atmospheric Corrosion Tests With Iron, Copper, and Zinc Extending Over Three Years, at Czechoslovak Testing Stations. K. Barton and Z. Bartonova. *Werkst. Korros.*, v. 20, No. 2, 1969, pp. 87-93 (German). **

Carbon steel (C 0.10; Cu 0.12; P 0.013; S 0.032), Zn (98.6 percent, rest Pb, Bi, Fe, Cu, Cd), and Cu (99.5 percent, rest Ca, Ag, Sn) were exposed for 1050-1063 days at Hurbanovo (A), Usti n. L. (B), and Prahaletnany (C). The cumulative time of electrolyte film formation (7083 to 10,502 hrs.) and the average temperature (7.5-8.1°) were determined from climatograms. The cumulative SO₂ adsorption in g/m₂ was 6.40 at A, 38.11 at B, and 68.66 at C. Steady state corrosion rates in the presence of electrolyte in g/m²-hr., in the order Fe, Zn, Cu, were at A: 0.0257, 0.0033, 0.0037; at B: 0.0332, 0.0032, 0.0037; and at C: 0.1110, 0.0108, 0.0105. A critical atmosphere SO₂ content can be expected for zinc and copper which depends on the adsorption equilibrium. The rust formed on iron chemically binds SO₂ up to a limit which then has no influence on the corrosion rate.

31. Influence of Chromium on the Atmospheric-Corrosion Behavior of Steel. R. J. Schmitt and C. X. Mullen. ASTM STP 454, American Society for Testing and Material, 1969, pp. 124-136.

Specimens of steel containing 0.5 to 28 percent chromium were exposed to industrial, semirural, moderate marine, and severe marine atmospheres for up to 8 years. Measurements of weight losses and number and depth of pits showed that less than 2 percent chromium decreased corrosion resistance; resistance gradually increased at 2 to 12 percent chromium; no corrosion occurred at less than or equal to 12 percent chromium in semirural and industrial atmospheres and at more than 15 percent chromium in marine atmospheres, although pitting occurred in the latter up to 28 percent chromium.

32. Mechanism of Atmospheric Corrosion of Steel. D. Dasgupta. Br. Corros. J., v. 4, May 1969, pp. 119-121.

The increased rate of corrosion of steel owing to the presence of sulphur, ammonia, and chlorine in the atmosphere has been studied by many investigators throughout the world. This review discusses critically the existing hypotheses regarding its mechanism and attempts to correlate the work of various investigators.

33. Minimum Paint Film Thickness for Economical Protection of Hot-Rolled Steel Against Corrosion. J. D. Keane, W. Wettach and W. Bosch. J. Paint Technol., v. 41, No. 533, 1969, pp. 372-382*.

A 10-year paint exposure study was conducted to determine whether there was a minimum or optimum paint film thickness for the economical protection of hot-rolled steel. Paint types tested included oil, alkyd, chlorinated rubber, epoxy ester, zinc-free phenolic, and nonchalking vinyl. Panels were exposed at rural, industrial, and seashore sites. Each additional mil of paint thickness used was accompanied by an increase of approximately 20 months in paint life. For each coating and surface type, there was a minimum initial paint film thickness above which long-term protection was obtained in each environment for the entire study period. This minimum effective thickness was lower for more durable paints and milder environments. The critical thickness was decreased only slightly by better surface preparation. Relatively little difference between plates with 1 and 2 mils of primer coating was observed as long as the proper film thickness of the system was obtained. The initial application of a sufficiently heavy film was much more economical than more frequent maintenance painting. The relative economy of various paint systems is discussed.

34. Painting of Metal Sprayed Structural Steelwork--Report on Conditions of Specimens after Five Years' Exposure. J. F. Stanners and K. O. Watkins. Australasian Corrosion Eng., v. 13, No. 10, October 1969, pp. 7-17.

The performance of steel plates and channels protected by various composite systems (metal spray plus paint) after five years' exposure to five natural environments is reported. Industrial, industrial-marine, and tropical-marine environments, half-tide immersion in seawater and full immersion in river water were investigated. In marine environments sprayed aluminum performed better overall than sprayed Zn; in industrial

environments and in river water little difference was observed in the metals as a substrate for paint.

35. Protective Coatings for Highway Structural Steels. J. D. Keane. National Cooperative Highway Research Program, Report 74, Highway Research Board, 1969, 64 pp.

The most generally accepted method of providing corrosion protection for the steel members of highway bridges and other structures is painting. This report contains a current state-of-the-knowledge with regard to painting of highway structural steel, based on a thorough review of the literature and current practice, an inspection and evaluation of more than 4,000 paint exposure tests, and the conduct of paint film thickness measurement studies. Due to the comprehensive nature of the investigation dealing with factors that influence paint selection, such as performance, appearance, costs, availability, and air pollution requirements, the report will be of interest and value to a wide range of highway personnel, including materials, maintenance, and bridge engineers, and specifications writers. The specific recommendations are summarized for typical preferred paint systems (including surface preparation, pretreatment, application methods, thickness, primer, intermediate coat, and finish coat) for various environmental exposure conditions, will materially aid highway agencies in the selection of suitable steel coating systems, and are sufficiently explicit to permit direct application.

36. Studies on Corrosion of Metals Provoked by Gaseous Pollutants. B. Sanyal, G. K. Singhanian and D. V. Bhadwar. Proc. 3rd. Intern. Congr. on Metallic Corrosion, Moscow (1966), Swets-Zeitlinger, Amsterdam, Holland, v. 4, 1969, pp. 454-464.

The corrosion of ferrous and nonferrous metals by air-containing moisture and sulfur dioxide has been studied under different exposure conditions with a view towards studying the effect of each factor--humidity, concentration of sulfur dioxide, surface area, period of exposure--on corrosion rates. Corrosion of mild steel is affected by the presence of other metals placed in proximity (not in contact) with steel, only when sulfur dioxide is present in a limited amount. The influence of pre-exposure of mild steel to a sulfur dioxide atmosphere on its subsequent behavior in pollution-free atmosphere has been investigated. The period of exposure, relative humidity and concentration of sulfur dioxide during pre-exposure determined the corrosion rates during subsequent exposures. The effect of other corrosive gases, for example, ammonia and hydrogen sulfide, has also been studied.

1968

1. A Statistical Evaluation of Atmospheric, In-Service, and Accelerated Corrosion of Stainless Steel Automotive Trim Material. H. L. Black and L. W. Lherbier. Metal Corrosion in the Atmosphere, ASTM STP 435, American Society for Testing and Materials, v. 3, 1968, pp. 3-32.

Stainless steel panels with various surface finishes were exposed to winter salt and ash conditions on trucks and automobiles, salt atmosphere, industrial atmosphere, and rural atmosphere for periods of one to four years. They were also evaluated by six accelerated tests either presently used by, or proposed by, the automobile industry.

Comparisons of the average results of the multiple specimens were made in an attempt to determine the relative superiority among the grades of stainless steel and among the surface finishes in each exposure environment. Statistical correlation coefficients were calculated to determine the degree of corrosion resistance correlation among the sites and to determine the correlation between "in-service" corrosion and the accelerated tests.

No clear superiority of any grade in all environments could be determined. With the exception of chromium flash plating, no surface finish tested was significantly superior to any other. The automobile and truck exposures showed that the varying weather conditions from one winter to another could cause unpredictable, conflicting results. The correlation between corrosion resistance and temperature, snow-fall, and de-icing agents, was not clear. The statistical correlation analysis conducted showed that very limited or no correlation exists between inservice corrosion and accelerated tests. Even among the tests, the correlation was poor or not existent. This study indicates that none of the accelerated tests evaluated can be expected to predict stainless steel corrosion performance in service.

2. Atmospheric Corrosion of Carbon and Low Alloy Cast Steels. W. Briggs. Metal Corrosion in the Atmosphere, ASTM STP 435, American Society for Testing and Materials, 1968, pp. 271-284.

Nine carbon and low-alloy cast steels cast in panel form, some machined and other unmachined, were exposed in marine and industrial atmospheres for periods of one-, three-, seven-, and 12-years and recorded as to weight loss information. The weight loss was converted to corrosion rate in terms of inches penetration per year (ipy) and milligrams lost per square decimeter per day (mdd). Comparisons were made and cast steels containing nickel, copper, or chromium as alloying elements have corrosion resistance superior to carbon cast steels or those containing manganese when exposed to atmospheric environments. Increasing the nickel and copper contents of cast steel increases the corrosion resistance in all three atmospheric environments. Unmachined cast steel surfaces with the casting "skin" intact, had no significant effect on the corrosion resistance of cast steels when compared to machined surfaces regardless of the atmospheric environment.

3. Corrosion of Metals by Aqueous Solutions of the Atmospheric Pollutant Sulfurous Acid. W. McLeod and R. R. Rogers. Electrochem. Technol., v. 6, No. 7-8, July-August 1968, pp. 231-235.

The corrosion rate of a metal in an acid with a normality between N/1 and N/10,000, such as H_2SO_3 , HNO_3 , H_2SO_4 , or HCl , was found to be related to the concentration of the acid in accordance with the equation: corrosion rate equals $\alpha \times$ (acid normality) to the B power,

where α and B are constant for each combination of acid and metal and where temperature is 25°C. By determining the values of α and B for a number of acid-metal combinations, it was possible to compare the corrosion rates of the various metals in sulfurous acid with those of the same metals in nitric, sulfuric, and hydrochloric acids, and to determine the corrosion rate of the metals in sulfurous acid of different normalities. Data obtained show that nonstainless steel, with or without nickel, is highly susceptible to sulfurous acid corrosion. However, when a substantial proportion of chromium is present in an alloy which contains nickel, steel is free from corrosion by either sulfurous acid or nitric acid. Copper and chromium are not appreciably susceptible to sulfurous acid corrosion in solutions lower than N/1.3. Tin corrodes more rapidly than other nonferrous metals between N/100 and N/1,000, but less than cadmium and zinc at N/10. Cadmium, and zinc corrode more rapidly in sulfurous acid than in nitric acid. Lead corrodes less rapidly in sulfurous acid than nitric acid. Aluminum is rapidly corroded by hydrochloric acid but less so by nitric or sulfurous acid. The study concludes that sulfurous acid solutions causing the greatest damage in urban and industrial areas have normalities between N/1 and N/10,000.

4. Corrosion Rates of Mild Steel in Coastal, Industrial, and Inland Areas of Northern California. H. E. Thomas and H. N. Alderson. Metal Corrosion in the Atmosphere, ASTM STP 435, American Society for Testing and Materials, 1968, pp. 83-94.

The corrosion rate of mild steel specimens was determined at 15 sites in northern California. Weight loss with time was measured. These sites included coastal marine, bay, and steam-geyser areas. The methods of specimen preparation, corrosion product removal, and exposure location details are covered. The repeatability of the tests was checked and found to be good at two locations, and the agreement with ASTM results at the Point Reyes exposure test site was reasonably good.

5. Corrosion Test Results on Fifteen Ferrous Metals After Seven-Years Atmospheric Exposure. G. B. Mannweiler. Metal Corrosion in the Atmosphere, ASTM STP 435, American Society for Testing and Materials, 1968, pp. 211-222.

This is a progress report covering findings on the removal of ferrous corrosion specimens that had been exposed for seven years to the atmospheres of five different test sites, which included rural, marine, and industrial environments. The materials employed were ten malleable and pearlitic malleable iron, two ductile irons, and three rolled steels. Previous removals of companion sets of specimens had been made after one- and three-years' exposure. The appearance of the corroded plates and weight losses were evaluated.

6. Corrosiveness of Various Atmospheric Test Sites as Measured by Specimens of Steel and Zinc. ASTM Committee G-1. Metal Corrosion in the Atmosphere, ASTM STP 435, American Society for Testing and Materials, 1968, pp. 360-391.

During the period 1948 to 1955, specimens of carbon steel and zinc were used to calibrate the corrosivity of the atmosphere in some 19 sites in the United States and Canada. In the period of 1960 to 1964 the study was expanded to include some 46 sites around the world.

As in the earlier study, the results at State College, Pa., were considered as unity and the corrosivity of the other locations were ranked in terms of the corrosivity of the atmosphere at State College. Differences in corrosivity between the two exposure periods were noted in some instances, while in others the atmosphere appeared to remain constant in its action on the two test metals.

In a number of instances the corrosivity of the atmosphere toward steel was greater than its effect toward zinc. In other instances the reverse situation prevailed. In a substantial number of locations the atmosphere was equally aggressive towards steel as it was towards zinc.

When the ratio of the two-year losses between steel and zinc were studied, it was evident that in characteristically industrial locations the ratio was 20 or less; whereas in predominantly marine locations it exceeded 20 and ranged as high as 364.

In calibration tests involving the corrosivity of a marine site at elevations of 60 ft, 30 ft, and ground level, there was little discrimination between elevations by the zinc specimens, but there was substantial discrimination by the steel specimens.

7. Effect of Various Factors on the Atmospheric Corrosion of Steel. S. R. Addanki, K. P. Mukherjee, A. K. Lahiri, and T. Banarjee. Tr. Mezhdunar. Kongr. Korroz. Metal, 3rd (1966), edited by N. D. Lesteva, Izd. "Mir", Moscow, USSR, v. 4, 1968, pp. 564-576 (Russian).

Corrosion resistance of mild and low-alloy, low-copper (0.05), and copper-bearing (0.24 percent) steels were determined at Jamshedpur (industrial) and Digba, West Bengal (coastal conditions). The corrosion rate decreased gradually at Jamshedpur indicating that the surface was protected by the formed rust (oxide film). Corrosion rates were highest for the horizontally positioned specimens and were lowest for the vertically positioned ones. The composition of the oxide film varied with the angle of incline and steel composition. The oxide film formed in the initial stages was highly porous and held water. On aging the oxide layer became denser and adhered well to the metal surface, especially if the corrosion resistance of the base metal was high. The corrosion resistance of the base metal was improved by increasing its copper content from 0.01 to 0.04 percent; increases beyond 0.04 percent copper had positive effects but to a lesser degree.

8. Gas-Volumetric Measurement of Atmospheric Corrosion. K. Bohnenkamp. Werkst. Korros. v. 19, No. 9, 1968, pp. 792-795 (German).**

The rate of corrosion of structural steel blanks at 30 square centimeter surface area was followed by the consumption of oxygen in a glass apparatus. By comparison with the weight of corrosion products, the average composition was between Fe_2O_3 and Fe_3O_4 . Clean samples in pure oxygen saturated with H_2O at 21°C and 150 torr showed negligible corrosion in 40 days, even when moisture condensed on the metal. The initial

addition to the oxygen of 1.05 g SO₂/sq m of sample produced a constant corrosion rate of 10 g Fe/sq m-day and daily additions of 0.21 g SO₂/sq m for 5 days gave the same initial rate, decreasing to approximately 4 g Fe/sq m-day after the SO₂ additions were stopped. Similarly, the initial addition of 1.4 g CO₂/sq m produced a corrosion rate of 4 g Fe/sq m-day. Specimens that were exposed to outdoor weather for 2 weeks continued rusting in the moist oxygen atmosphere without the addition of SO₂. At 90 percent relative humidity the corrosion rate was 1/5 that at 100 percent relative humidity for the same initial addition of SO₂.

9. High Pressure Electrical Contacts. J. King. Proc. 1968 Electrical Components Conference, May 8-10, 1968, pp. 454-458.

Satisfactory performance has been achieved with high pressure contacts of uncoated base metals. These contacts were neither protected from, nor deliberately exposed to contamination. Variations of both point and line contact configurations have been evaluated and their performance falls into predictable patterns. Sufficient test data has been evaluated and the following conclusions can be drawn: (1) tarnish films on base metal are penetrable by high pressure contact indentors without resorting to a wipe motion; (2) line contact chisels and point contact cones with large included angles are superior to thin knife-like or needle-like contacts; (3) relative contact hardness is important in that both indenter and flat contact target must deform to expose base metal or the resulting interface will consist of one contact with bare metal exposed and in direct contact with the insulating tarnished surface of the other contact.

10. Investigations Carried Out in Sweden on the Atmospheric Corrosion of Stainless Steels. S. Henrikson, A. Karlsson, O. Steensland and G. Steenas. Chapt. 21 in Proc. 5th Scandanavian Corrosion Congr., Copenhagen, v. 2, 1968.

Specimens of Cr, Cr-Mn-Ni, and Cr-Ni-Mo steels with different surface finishes have been exposed at test stations with typical rural, city, industrial, and marine atmospheres. The results of the first five years of exposure are presented in this paper.

11. Investigations of the Corrosion-Causing Properties of Volatile Acids and Anhydrous Acids. E. Iaengle. Eidgenoessische Technischen Hochschule, Zurich, Switzerland. Ph.D. Thesis, 1968, 43 pp. (German).

The corrosion resistance of Fe, Zn, Al, Cu, and Pb to chemical attacks from hydrochloric acid, hydrogen sulfide, formic acid, acetic acid vapors, and sulfur dioxide atmospheres were studied. Emphasis was placed on the problems of critical vapor humidity, analytic determination of corrosion products, and the reaction mechanisms. Metal sample were briefly exposed to dry or moist acid vapors during the introductory period and subsequently kept for a longer time in an acid-free atmosphere of different moisture levels. Results showed that the metal surface was initially attacked by the formation of a dry or humid saline crust which

liquefied through atmospheric water absorption and attacked the metal surface by deoxygenation. Pronounced reactions were observed on iron and zinc surfaces, but the other metals proved relatively corrosion resistant.

12. Measurement of Atmospheric Factors Affecting the Corrosion of Metals.
H. Guttman and P. J. Sereda. Metal Corrosion in the Atmosphere, ASTM STP 435, American Society for Testing and Materials, 1968, pp. 325-359.

Atmospheric factors, namely, time of wetness of corroding metal panels, panel temperature, and atmospheric sulfur dioxide and atmospheric chloride content, were measured at four inland and three coastal North American test sites while corrosion data for steel, copper, and zinc were being developed. Corrosion losses experienced by panels of these metals which were exposed at different times of the year for similar periods of time showed considerable variation at all sites.

Statistical analyses show conclusively that the atmospheric factors measured completely control the rates of corrosion at all sites for at least the initial month. For longer periods of time, control of the corrosion process remains with the atmospheric factors in some cases, and in others it is gradually transferred to factors related to the changing surface conditions resulting from accumulation of corrosion products and foreign agents.

At the sites where atmospheric factors control corrosion, the empirical equations developed enable one to predict the corrosion losses of steel, copper, and zinc from a knowledge of the atmospheric factors. They also make it possible to account for variations in observed corrosion losses experienced by panels exposed at different times of the year.

13. Mechanism and Kinetics of Corrosion in a Moist Atmosphere in the Presence of Hydrogen Chloride Vapors. K. Barton and Z. Bartonva. Tr. Mezhdunar. Kongr. Korroz. Metal, 3rd (1966), edited by N.D. Lesteva, Izd. "Mir," Moscow, USSR, v. 4, 1968, pp. 493-506 (Russian).

Analyses of corrosion products formed on carbon steel (C 0.08, S 0.024, P 0.02, Mn 0.31, and Cu 0.08 percent), Zn (99.9 percent), and Cu (99.98 percent) in the course of 32 days when exposed to relative humidities of 70-95 percent at 20, 30, 40, and 50° in static and mobile atmospheres and HCl concentrations of 0.0007-0.001 vol. pct. pointed to a stabilized state in which the corrosion-time relation was linear and the composition of corrosion products formed was constant. Corrosion of steel was controlled by the rate of the chemical reactions, and of zinc and copper by the diffusion of HCl and H₂O to, and adsorption at, the boundary of corrosion products with the atmosphere, and the transition of insoluble products into soluble products. Thus, at high temperatures and humidities, the formation of corrosion products containing high amounts of oxides and the reduced HCl adsorption decreased the corrosion rate of copper and zinc.

14. Microstructure and Growth of Layers of Rust on Steels During Atmospheric Corrosion J. B. Horton, W. S. Hahn and J. F. Libsch. Tr. Mezhdunar. Kongr. Korroz. Metal., 3rd (1966), edited by N. D. Lesteva, Izd. "Mir", Moscow, USSR, v. 4, 1968, pp. 411-417 (Russian).

Investigations (with an optical microscope) were made on the structure of a corrosion layer formed on steel of Mayari-R type containing: C 0.08, Mn 0.07, P 0.10, S 0.03, Si 0.28, Ni 0.40, Cr 0.60, and Cu 0.60 percent, and kept for 17 years in a town atmosphere, as well as on the same steel and low-carbon steel placed in an industrial atmosphere for 4 years. It was established that rust has a 2-layer structure: an external, porous layer with atmospheric dust present, and an internal (free of dust) which adheres closely to the base. During rainy weather the fissures and pores filled up, contacting air with fresh rust which absorbed atmospheric dust. During dry weather, rust forms in the layer adhering to the steel surface and does not contain any atmospheric dust.

15. Patina on Old Metal Objects. J. Lehmann. Monographs of the National Museum in Pozan, v. 2, 1968, pp. 1-125 (Polish).

This is a mimeographed excerpt from a doctoral thesis on the concept of patina and its composition and structure. Methods applied for investigations include: chemical analyses (spectrographic and colorimetric), microscopic observations, X-ray diffraction, X-ray defectoscopy, micrometallography and electron microscopy (replica). A brief summary of kinds of patina on different metal objects is presented. Gold, silver, bronzes, tin, lead, and iron were considered.

16. Rate of Corrosion of Plain Carbon and Low-Alloy Structural Steels. W. Schwenk and H. Ternes. Stahl Eisen, v. 88, No. 7, 1968, pp. 318-321 (German).

Corrosion tests of 3 steels containing 0.12 percent carbon and increasing amounts of copper (0.10 to 0.27 percent) and of a weather resistant steel containing C 0.09, P 0.13, Cr 0.85, Cu 0.34, and Ni 0.32 percent were conducted under natural weathering conditions in industrial air at different locations for a test period of 4 years. The data obeyed the general rules for the corrosion rate of unalloyed and low-alloy steels. The rate of rust formation of these steels was essentially related to the way the rust layers formed, regardless of the test location used.

17. Role of Copper (II) in the Oxidation of Ferrous Hydroxide Colloid With Special Reference to the Corrosion of Iron in a SO₂-Containing Environment. K. Inouye. J. Colloid Interface Sci., v. 27, No. 2 June 1963, pp. 171-179.**

Air oxidized ferrous hydroxide colloids doped with Cu²⁺ at less than or equal to 6.5 copper-iron wt-pct were studied. At 1 to 3 percent copper-iron (0.25 to 0.5 percent copper is added to common

"antiweathering" high-strength steels), sedimentation volume reached a remarkable minimum, and the dimension of primary colloidal particles (composed of $\text{Fe}(\text{OH})_2$ and minute Fe_3O_4 crystals) were maximum. The oxidized colloids were then dried to form layers of model corrosion products. Permeability of argon and diffusion of N_2 through the oxide layers indicated that the dried oxides are more compact in the low range of copper-iron ratios. The mechanism of effect of copper on the oxidation of $\text{Fe}(\text{OH})_2$ colloid and on the formation of a particular secondary structure is discussed.

18. Stability of Metal Coatings in Corrosive Media. A. Kovachev, N. Stoyanova, M. Boncheva, S. Simov, S. Avramova, B. Grigorov and B. Gochev. *Elektroprom. Priborostr.*, v. 3, 1968, pp. 105-107.

The following electroplated (except as indicated) metal coating were tested: Zn (30 μm); Cd (30 μm); Cu + Ni + Cr (20 + 10 + 0.5 μm); chemically plated Ni (10 μm); Sn (30 μm); Ag (20 μm); nitrided steel. These materials were tested in SO_2 , HCl, Cl_2 , SO_3 , N_2O_3 , and NH_3 gaseous media. The cadmium and silver coatings withstood the HCl media. Only the nitrided steel failed in SO_3 , and only the cadmium coating failed in NH_3 . The silver was the only satisfactory coating in Cl_2 .

19. Survey of Corrosion and Atmospheric Pollution in and Around Sheffield. K. A. Chandler and M. B. Kilcullen. *Brit. Corros. J.*, v. 3, 1968, pp. 80-84.

The nature and extent of the relationships between the corrosion of two mild steels of different copper content, and atmospheric pollution were investigated at 22 selected sites in the Sheffield area. This was part of a general investigation into atmospheric corrosion of ferrous metals. The results confirmed that there was an important relationship between the corrosion of steel and the atmospheric pollution by smoke and sulfur dioxide. However, only about 50 percent of the variations in corrosion rates at different sites could be attributed to sulfur dioxide measured in this investigation by the Volumetric Method. Smoke intensity had an influence on the corrosion rate of steel similar to that of sulfur dioxide but the correlation between sulfur dioxide and smoke was high, so that their effect on the corrosion rate could not be considered as independent. Their combined effect was only slightly greater than their individual effects. The corrosion rate could not be accurately predicted from a knowledge of the quantity of these two types of atmospheric pollution present in the atmosphere.

1967

1. Atmospheric Corrosion Resistance of Low-Alloy Steels. H. K. Moss. *Australasian Corrosion Eng.*, v. 11, No. 12, Dec. 1967, pp. 19-24.

Susceptibility of low-alloy steels to atmospheric corrosion is discussed. The mechanism of atmospheric corrosion depends on chemical

compounds formed between steel and environment which affect both physical and chemical properties of rust films. The results of investigational work are shown graphically. Paint durability, mechanical properties, welding, and economics of low-alloy steels are discussed.

2. Atmospheric Corrosion Studies in Two Metropolitan Areas. J. B. Upham. J. Air Pollution Control Assn., v. 17, No. 6, June 1967, pp. 398-402.

Atmospheric corrosion studies using established air monitoring network sites were conducted in metropolitan St. Louis and Chicago to obtain information on the quantitative relation between mean pollution levels and corrosion losses on ferrous metals. Studies are described and data are presented showing good correlation found between corrosion losses and sulfur-related pollutants, and insignificant effect of dustfall and suspended particulate matter.

3. Bridging With Steel. J. A. Cran and I. M. Park. Engineering J., February 1967, pp. 18-25.

The first iron bridge was built across England's Severn River in 1779. Since the erection of this 100-foot arch, bridge technology has been continually advancing. This progress has been greatly assisted by the iron and steel industry. For example, the advent of high-strength steel with excellent weldability has contributed to better bridges. In addition, the metallurgical properties of steel are continually being investigated. Unfortunately, the results of these investigations are highly metallurgical in form and it is difficult for a designer to relate them to his practical problem. The main purpose of this paper is to apply such results to bridge design.

The first portion of the paper has three areas of discussion: (1) corrosion protection; (2) fatigue behavior; and (3) notch toughness and brittle fracture. The principles outlined in the first portion of the paper are incorporated in a unique series of charts. These charts categorized bridges. Specific steel grades are then suggested for each type of bridge. It is hoped that these charts will greatly assist bridge designer in the selection of a steel.

4. Corrosion by Air Pollution. J. R. Goss. Proc. Annu. Conf., Nat. Soc. Clean Air, No. 34, 1967, pp. 75-92.

A literature review is given on the chemical and physical effects of air pollution on the corrosion of stonework and building materials, metals (Al, Cu, Fe, Pb, Zn, Au, Ag), textiles, leather, paper rubber, and paint. A short section on the costs of corrosion is also included.

5. Corrosion Properties of Iron and Steel. H. J. Cleary and N. D. Greene. Corrosion Science, v. 7, No. 12, Dec. 1967, pp. 821-831.

Multiple correlation analysis has yielded results which permit prediction of the corrosion rate of alloy steel as function of its minor

element content. Phosphorus and carbon are particularly detrimental to corrosion resistance, as is manganese when present in large amounts. Silicon also lowers resistance, while copper is mildly beneficial. Sulfur, chromium and nickel have no effect on corrosion rate in these low alloys. Corrosion rate is also dependent on distribution of iron carbide in microstructure. For example, the dissolution rate is increased markedly by decreasing average pearlite lamellae spacing in a given alloy.

6. Mechanism of the Corrosion of Fe, Zn and Cu in a Humid Atmosphere Containing HCl Vapors. K. Barton and Z. Bartonova. Collect. Czech. Chem. Commun., v. 32, No. 7, 1967, pp. 2431-2438 (German).

During the corrosion of Fe, Zn, and Cu in an atmosphere of over-critical humidity and of the HCl concentration of 7×10^{-4} to 2×10^{-3} volume percent, a steady state is slowly established which is characterized by the constant composition of the corrosion products and by the linear dependence of corrosion versus time. With iron, the kinetics is controlled by the chemical HCl regeneration in the rust formation and by the subsequent HCl action. With zinc, the rate-controlling process is the reaction of the corrosion products (hydroxide and basic chloride) with HCl under formation of the solution $ZnCl_2$. With copper, the decisive step is the destruction of the $CuCl$ layer which is on the Cu_2O layer under formation of a solution product. In both last cases, the rate controlling process is affected by the transport of gaseous HCl to the product-atmosphere boundary, by the HCl adsorption, and by the composition of the product. In the last named case, $Cu_2(OH)_3Cl$ is formed. At higher temperatures and comparable relative humidities, products with higher hydroxide content are formed, and the HCl adsorption and the corrosion rate decreases, especially with zinc and copper.

7. Soiling and Materials-Damage Studies. Chapt. 4 in Economic Costs of Air Pollution. R. G. Ridker. F. A. Praeger, New York, N.Y., 1967, pp. 57-89.

There is little doubt that air pollution can and has caused substantial losses due to soiling and deterioration of materials. Its role is well documented in experiments with test panels and experience gathered from major episodes. But estimates of the costs associated with materials damage due to normal levels of air pollution are very poor, and marginal cost estimates are virtually nonexistent. Furthermore, nothing is known about how firms and households adjust--whether, for example, they clean more frequently or more intensively, or simply suffer the additional dirt. The chapter reports on a number of attempts to develop such information in typical urban settings.

8. Tests Show Performance of Low Alloy Steels in Chemical Plant Environments. R. J. Schmitt and W. L. Mathay. Materials Protection, v. 6, No. 9, 1967, pp. 37-41.

The corrosion factors and economic aspects of two high-strength low-alloy steels as materials of construction for chemical plant

structures are discussed. The steels are compared in various chemical plant environments with carbon steel, a common material for these structures. The higher cost and better corrosion resistance of the high-strength low-alloy steels are explained in an economic context.

1966

1. Accelerated Atmospheric Corrosion--A Laboratory Test. I. Geld and F. J. D'Oria. Mater. Protect., v. 5, No. 3, 1966, pp. 16-19.

Atmospheric corrosion was accelerated approximately 26 times the normal rate in New York Harbor by using a concentration of SO_2 of approximately 4 $\mu\text{g/l}$. This was obtained by passing air at a measured rate through two flasks containing "SO₂ generating solution" and by using the solution in the desiccator in which specimens were exposed. The flasks and desiccator were maintained at $95 \pm 1^\circ \text{F}$. The "SO₂ generating solution" consisted of 50 g $\text{Na}_2\text{S}_2\text{O}_5$ and 110 g Na_2HPO_4 in 500 ml distilled water. The pH was adjusted to 6.45 by addition of small amounts of one or the other components. The equilibrium concentration of SO_2 was about 10 $\mu\text{g/l}$ with no specimens present, but this fell to approximately 4 $\mu\text{g/l}$ when the pickled and washed mild steel specimens were exposed. After 20 hours, specimens were unspotted and uniformly coated with an adherent rust film (thinner at lower coupon edges). The rust was dark brown and sufficiently adherent to prevent transfer when rubbed lightly. The extent of rusting was approximately 14 mg/in^2 of surface, approximately equal to the amount of rust formed in 22 days shed exposure. This type and degree of rusting are considered adequate to evaluate differences in effect of various rust-preventive treatments. The theory of corrosion in the presence of SO_2 is discussed, as well as the reactions involved in the "SO₂ generating solution."

2. Atmospheric Corrosion of Metals. N. D. Tomashov. Chapt. 14 in Theory of Corrosion and Protection of Metals, MacMillan, 1966, pp. 367-396.

The different forms of atmospheric corrosion are classified by the degree of dampness of the corroding surface. Thus, three types can be distinguished: wet, moist, and dry atmospheric corrosion. Those three types proceed by significantly different mechanisms which are described. There are three types of condensation of moisture on corroding metal surfaces at a relative humidity less than 100 percent: the capillary condensation, the adsorption condensation, and the chemical condensation. An apparatus is designed to simulate the atmospheric corrosion and experimentally confirms that this proceeds by an electrochemical mechanism. The basic factors which determine the rates of atmospheric corrosion are listed. Wet and moist atmospheric corrosion are controlled primarily by cathodic and anodic processes. The various factors which determine the corrosivity of the atmosphere are: its composition (sulfur dioxide, dust, hydrogen peroxide, ammonia, etc.), humidity and temperature. Corrosion inhibitors and the methods of corrosion protection of metals are cited.

3. Atmospheric Corrosion of Metals at Bhavnagar. V. S. Rao. Indian J. Technol., v. 4, No. 5, 1966, pp. 159-161.

Monthly rates of corrosion of mild steel, zinc, copper, and aluminum were determined at Bhavnagar, representing a tropical marine site, during the 12 month period August 1961 to July 1962, under both open and sheltered exposure conditions. The data obtained were compared with those available for other places in India. In general, corrosion is lower during November to April than during May to October. No definite correlation has been observed between salinity and corrosion rate, indicating that factors like relative humidity and rainfall have a more pronounced effect than salinity on the corrosion rate at Bhavnagar.

4. Atmospheric Corrosion of Steel, Zinc, Cadmium, Copper, and Aluminum in Different Coastal and Continental Regions. G. K. Berukshtis and G. B. Klark. Corrosion of Metals and Alloys, Collection No. 2, Israel Program for Scientific Translations, Jerusalem, 1966, pp. 281-297.**

In attempting to find a more precise mathematical relationship between the rate of atmospheric corrosion of metals and the external conditions, the authors conducted tests which lasted for five years. This paper was based on the results of the first year. The rate of corrosion was expressed as a function of the temperature, the sulfur dioxide concentration, duration of exposure, and conditions of exposure.

5. Corrosion Behavior of Salt Powder Towards Various Metal. A. Bukowiecki and B. G. Joshi. Schweiz. Arch. Angew. Wiss. Tech., v. 32, No. 2, 1966, pp. 42-54.

Clean metal strips (75 x 20 x 1mm) of steel, Zn, Al, and Cu were exposed to 2 piles of salts, one at each end of the strip. The salts used were various chlorides, sulfates, carbonates, benzoates, phosphates, and nitrates. The specimens were placed in a desiccator at 20° for 7-days. Corrosion occurs if all H₂O is not excluded from the desiccator. A true solution need not be formed. A thin film of liquid suffices to induce corrosion.

6. Corrosion Behavior of Some Metallic Materials in Liquid Sulfur Dioxide. L. Rivola, T. Bazzan, M. Piro and G. Bombara. Proc. 2nd Intern. Congr. Metal. Corrosion, New York (1963), National Association of Corrosion Engineers, Houston, TX, 1966, pp. 418-423.

After a conductometric investigation on various electrolytes in liquid SO₂, (CH₃)₄NC10₄ was selected as the electrolyte for studying the corrosion behavior of metals in SO₂ because of its good conductance and the stability of its anion. A preliminary report is given on static corrosion tests in 1 g/l (CH₃)₄NC10₄ in liquid SO₂ at 60°C. One series of tests were run anhydrous; in the other, humid air was bubbled through the cell to add some moisture to the SO₂. Corrosion was greater under humid conditions. The metals employed were Mg, Zn, Al, Sn, steel, Pb, Ni, Cu, brass, bronze, stainless steel, Ag, Ti, Ta, W, Zr,

Au, and Pt. Weight loss is given in mg/sq dm-day in tabular form. Anodic corrosion tests were made on the same metals at 35° C. The anodic polarization curves are plotted. It is suggested that these data might serve as the starting point for a rigorous and extensive study of each individual metal in SO₂.

7. How Atmospheric Conditions Can Corrode Refinery Equipment. P. W. Sherwood. *Erodel Kohle* (Hamburg), v. 19, No. 4, April 1966, pp. 289-290 (German).

Atmospheric corrosion of refinery equipment from the effects of humidity, dusts, and electrolytes is reviewed. Effect of humidity: Although water vapor contributes to the mechanism of atmospheric corrosion, the principal offender is water which precipitates in liquid form from saturated or near-saturated air. An oxidation-reduction potential may be built up between two surfaces which promotes corrosion. Electrolytes dissolved in the water will increase corrosive action. Enclosed storage and humidity control are two approaches which can be used to counteract some of these situations. Effects of dust: These are probably not significant unless the dust consists of a salt or other kind of electrolyte. Effects of oxidants and electrolytes: Oxidants cause serious corrosion only in the presence of water. Acidic materials are seen to be the worst corrosive agents in the atmosphere. Salts are strong electrolytes and in the presence of water they will contribute to rusting of materials. Alkalies are not considered a serious problem in atmospheric corrosion; strong alkalies deposited in the presence of water can cause deterioration of aluminum or zinc.

8. Role of Ammonia in the Atmospheric Corrosion of Mild Steel. T. K. Ross and B. G. Callaghan. *Nature*, v. 211, July 2, 1966, pp. 25-26.

Considerations of surface tension of the catholyte resulting from electrochemical corrosion in the presence of ammonium salts and observations on the high ammonia content of the adherent rust in the initial stages of corrosion suggest that the ammonium ion has an effect on the atmospheric corrosion of mild steel. The principal effect of the ammonium ion is the promotion of surface wetting and hence, the involvement of greater areas of metal in the corrosion process, particularly during its initial stages.

9. Rusting in Air-Characteristic Properties of Natural Rusts. K. A. Chandler and J. E. Stanners. *Proc. 2nd Intern. Congr. on Metallic Corrosion*, New York (1963), National Association of Corrosion Engineers, Houston, TX, 1966, pp. 325-331 (Discussion 331-333).

The work described is the first stage of an investigation into the mechanism and kinetics of rusting. Mild steel panels were exposed in London in a vertical position, and were examined at intervals of 2 months. A series of layers of oxide is formed and hydrated. These layers break away. Some adhere but may be removed with a wire brush. Corrosion is not uniform. Pits form to a limiting depth of 50 µm, then the surrounding

steel is attacked at fresh places. The rust in the pits cannot be removed by brushing. Such rust often contains large salt crystals. Rusts contain sulfates, chlorides, NH_4 salts, and moisture. Moisture amounts to approximately 7 percent of the rust. Painting of steel that has rusted is not recommended, even after brushing or scraping, since the adherent layer still retains salts and moisture. It is suggested that for steel that is to be used bare a modification of the rusting mechanism to produce a strongly adherent form is in order. For steel that is to be painted, an easily removed rust is desirable.

10. Study of Corrosion of Iron and its Alloys in Chlorine and Sulfur Dioxide by the Thermographic Method. J. K. Tovmas'yan, B. S. Shevchenko and N. M. Gontmakher. *Zashchita Metal.*, v. 2, No. 2, 1966, pp. 194-200 (Russian).

Armco iron containing 0.025 percent carbon and cast iron containing 3.52 percent carbon were subjected to corrosion in gaseous chloride at 50°C, and U10A steel containing 1.04 percent carbon was subjected to corrosion in sulfur dioxide at 25.8°C, and rate of their corrosion was evaluated by measuring the temperature gradient, Δt , between specimen and the thermostat bath. As humidity of chlorine increased from 0.06 to 0.08 and 0.10 percent, the time of attaining maximum Δt for Armco iron and the cast iron diminished, and the corrosion rate of Armco iron increased by 4.7 and 7.7 times, respectively. The corrosion rate of the cast iron increased by a factor of 3 when the humidity of chlorine increased from below 0.06 and 0.08 percent. The time of attaining maximum Δt for U10A steel in SO_2 passed through a minimum in the humidity intermediate between 13.7 and 24.0 g/m³.

11. Sulfurous Acid Corrosion of Low Carbon Steel at Ordinary Temperatures-I. Its Nature. W. McLeod and R. R. Rogers. *Corrosion*, v. 22, No. 5, 1966, pp. 143-146.

Corrosion rate data are presented for low carbon steel in (1) a combination of sulfur dioxide, water vapor and air, and (2) aqueous solutions of sulfurous acid in the absence of air, at ordinary temperatures. Information as to the nature of the corrosion products is presented and it is shown that this depends on the place in which the corrosion takes place to an important extent.

12. The Influence of Salts in Rusts on the Corrosion of the Underlying Steel. K. A. Chandler. *Brit. Corros. J.*, v. 1, No. 7, 1966, pp. 264-266.

A series of synthetic rusts was prepared with a range of sulphate and chloride contents. The samples were placed on steel specimens and after a test period of 30 days at different relative humidities, the corrosion of the underlying steel was measured. The presence of salts caused increased corrosion of the steel and this increased with the amount of salt in the rust. Corrosion was inappreciable below a relative humidity of about 40 percent.

13. The Seasonal Distribution of Ferrous Sulphate Formed During the Atmospheric Rusting of Mild Steel. T. K. Ross and B. G. Callaghan. Corrosion Sci., v. 6, No. 7, 1966, pp. 337-343.

An electron micro-probe analysis of rust formed by atmospheric corrosion of mild steel in an industrial atmosphere was carried out to study the effects of the time of year, with special attention to the effects of SO₂. Summer-exposed specimens contained a low overall sulfur content at the metal surface while winter-exposed material had a high sulfur content with sulfur bonding. Under spring conditions sulfur moved through the oxide to the latter's surface and formed "nest" structures. SO₂ and water provide a source of electrochemical activity to allow sulfate, formed at anodic areas, to remain close to these areas. In the absence of such activity, sulfate diffused through the rust under concentration gradient forces.

1965

1. Atmospheric Corrosion of Important Systems of Base Metals and Metallic Coatings. K. Muller. Korrosion, No. 17, 1965, pp. 64-68 (German).**

The electrochemical nature of the atmospheric corrosion of metallic systems is reviewed. Quantitative data with respect to atmospheric components are tabulated and equations for the electrolytic reaction in the metal/solution, metal₁/metal₂/solution are presented. Two metals in conductive contact represent a galvanic couple and their relative corrosion is determined by their respective corrosion currents. If the less noble metal is the base and the nobler metal forms the coating, the base metal protection depends on a continuous protective layer free of defects and porosity. A less noble metal applied as a protective coating will protect the nobler base metal even with a discontinuous film formation but will be sacrificed in the process.

2. Atmospheric Corrosion of Steels Related to Meteorological Factors in Japan. II. Multiple Correlation of Meteorological and Atmospheric Pollution Substances on Corrosion of Steel. K. Oma, T. Sugano, T. Ueki and Y. Hirai. Boshoku Gijutsu, v. 14, No. 1, 1965, pp. 16-19 (Japanese).

The atmospheric corrosion rates of steels were measured in an industrial district (Koto-Ku) of Tokyo. The correlations between corrosion rates and meteorological factors or atmospheric pollution substances were studied statistically. The corrosion rate was expressed by $y = -136.91 + 0.05x_1 + 2.56x_2 + 0.12x_3 + 3.60x_4 - 24.63x_5 + 2.0x_6 - 14.37x_7 + 13.43x_8 + 3.65x_9 - 1351.99x_{10}$, where y is the corrosion rate in mg/day-dm², x_1 = temperature, x_2 = relative humidity in percent, x_3 = precipitation in mm, x_4 = SO₂ gas in mg/day-dm², x_5 = sea salt particles in mg/dm², x_6 = wind velocity in m/sec, and x_7, x_8, x_9 , and x_{10} are the amounts, respectively, of soluble substances, insoluble substances, sulfate, and tar substances expressed in g.

3. Atmospheric Corrosion Products of Some Commercial Metals. H. J. Meyer. Korrosion, No. 17, 1965, pp. 44-52 (German).**

The chemical composition and phase structure of corrosion layers formed on Fe, Cu, Zn, and Al under normal atmospheric conditions is reviewed. Most layers consist of several crystalline phases and are frequently found in mixture with amorphous materials. A distinction must be made between primary and secondary films. Tabular data of the composition and and crystalline orientation of primary layers present the most important crystallographic characteristics of minerals such as oxides, hydroxides, sulfides, carbonates, chlorides, and nitrates and of corrosion products not yet identified as naturally occurring minerals. Corrosion products formed on Fe, Cu, Zn, and Al are discussed in detail with respect to formation, composition, crystallography and protective properties.

4. Atmospheric Corrosion Resistance of Stainless Steels. Experience in Germany. K. Janssen and R. Moser. Korrosion, No. 17, 1965, pp. 94-98 (German).*

Stainless steels containing 17% Cr, 18% Cr-8% Ni, and 18% Cr-10% Ni-2% Mo were exposed to rural, urban, industrial, and marine atmospheres. The 17% Cr stainless steel is not suited to exposed architectural applications. In rural and urban atmospheres 18/8 stainless steel was unaffected during one-year exposure but in strongly contaminated industrial atmospheres frequent cleaning is required or slight corrosion in the form of surface dulling must be accepted. Smooth surfaces are advantageous in particularly corrosive atmospheres.

5. Atmospheric Corrosion Resistance of Stainless Steels. Experience in Great Britain and the United States. T. E. Evans. Korrosion, No. 17, 1965, pp. 87-93 (Germany).**

Thirty years' experience in the USA has proved 18/8 and 17/7 Cr-Ni stainless steels outstandingly corrosion resistant in urban, industrial and rural environments. In marine atmospheres 18/8 stainless steel is satisfactory if cleaned frequently; however, 18/8 stainless steel containing Mo is more resistant. In strongly contaminated industrial atmospheres of Great Britain, Cr-Ni stainless steels with 18% Cr, 10 to 12% Ni, and 2.5% Mo have proved more satisfactory than those without Mo in locations where regular cleaning is difficult. Earlier indications that urban industrial atmospheres in Great Britain are more destructive to certain grades of stainless steels than similar locations in the USA were fully confirmed. Data are presented regarding locations, steel grades, manufacturing history, heat treatment, specimen preparation, and comparative corrosion resistance.

6. Compares the Results of Electrochemical Measurements on Low-Alloy Steel With Their Behavior in Rusting. G. Becker. Archiv fur das Eisenhüttenwesen, v. 36, No. 7, 1965, p. 489 (German).

This paper compares the results of electrochemical measurements on low-alloy steels with their behavior in rusting. Electrochemical parameters of low-alloy steels were measured to determine a relationship with the results obtained from natural rusting tests. The relation between the degree of rust and steady and activation potentials is discussed.

7. Corrosion Rate of Plain Carbon Steels in Land, Sea, and Industrial Atmospheres. E. Brauns and U. Kalla. Stahl Eisen, v. 85, No. 7, 1965, pp. 406-412 (German).*

The corrosion rates of shipbuilding plain C rimmed steels, steels killed with Si, and those killed with Si and Al, manufactured by various sorts of melting, were determined in field tests in land, sea, and industrial atmospheres over a test period of 7 years. The composition of 7 steels tested was as follows: C 0.05-0.20, Si 0-0.25, Mn 0.35-0.65, P 0.015-0.074, S 0.016-0.041, Al 0-0.15, Cr 0.04-0.09, Cu 0.05-0.20, and Ni 0-0.09 wt. percent. The effect of Cu amount in steel was significant in the industrial atmosphere, the corrosion losses declining with the increase in Cu amount. In land and sea atmospheres the effect of Cu was negligible. An increase in Cu over 0.1% is almost without effect on corrosion rate. The increase of Cu from 0.05 to 0.20% decreased the corrosion rate by only 25%. The steels killed with Si showed a smaller corrosion rate than the rimmed steels with the same or even higher Cu in sea and especially the industrial atmospheres. The data of the corrosion rate showed that the corrosion behavior of all investigated steels was constant after 5 years of exposure. Samples brushed or pickled before weighing and testing corroded in the same way, though a thick layer of rust was left on the brushed samples.

8. Distribution of Sulphur in Corrosion Products Formed by Sulphur Dioxide on Mild Steel. T. K. Ross. Corrosion Science, v. 5, No. 4, April 1965, pp. 327-330.

The range of scales formed upon steel in variety of environments containing sulfur dioxide was examined using electron-probe micro-analysis. The most striking feature which these scales exhibit in common is that their sulfur content is not, as might be supposed, uniformly distributed throughout their cross section, but is located in narrow bands parallel to the surface. The composition of the bands is such that sulfur in excess of that corresponding to FeS is present.

9. Effect of Copper Content of Carbon Steel on Corrosion in Sulfuric Acid. E. Williams and M. E. Komp. Corrosion, v. 21, No. 1, January 1965, pp. 9-14.

Difference in corrosion rates observed for various steel samples was associated with differences in copper content. Surface condition and microstructure had an appreciable effect, whereas copper content of steel was the controlling factor determining corrosion rate. Electro-

chemical measurements indicated that copper dissolved in steel decreases the exchange current of the cathodic reaction in sulfuric acid solutions, thereby decreasing the corrosion rate.

10. Effect of Small Additions of Copper on Atmospheric Corrosion Resistance of Mild Steel. H. K. Moss. Australasian Corrosion Eng., v. 9, No. 1, Jan. 1965, pp. 19-23.

The mechanism of corrosion and the effect of painting and galvanizing on this mechanism is reported. Several high-strength low-alloy steels containing varying percentages of Cu, Ni, Cr, P, and Si showed extremely good resistance to atmospheric corrosion, with the presence of copper alone producing by far the greatest single benefit. The effect of copper on the strength of mild steel and the weldability of copper-bearing steels is discussed.

11. Electrochemical Mechanism of Atmospheric Rusting. U. R. Evans. Nature, v. 206, June 1965, pp. 980-982.

The experiments described here were made on specimens of mild steel, and relatively pure iron electrodeposited on steel, nickel, or copper substrate, and on unplated nickel. The samples were introduced dry into moist (95 percent relative humidity) unsaturated air containing 0.2 percent sulfur dioxide. Once FeSO_4 has appeared, rust-formation continues even though the sample is placed in moist air containing no sulfur dioxide. Oxidation and hydrolysis of the FeSO_4 produce H_2SO_4 which attacks more metal. The reaction is considered electrochemical in that Fe^{+2} is oxidized at the anode and O_2 or SO_2 is reduced at the cathode. The anodic attack proceeds in crevices, the cathodic reduction of O_2 to OH^- allows formation of $\text{Fe}(\text{OH})_2$ in the crevices. The $\text{Fe}(\text{OH})_2$ is quickly oxidized to the ferro-ferric and ferric condition and, thus, the formation of strong, adherent rust. The ferro-ferric matter is further oxidized to the ferric state and, thus, the ferric rust thickens by pick up of Fe^{+2} at the anode and O_2 at the cathode.

12. Electron and Microscopic Observations of Corrosion from Air-Borne Dust. R. Meldau. Korrosion, No. 17, 1965, pp. 37-43 (German).**

Various forms of the effect of dust on wear and corrosion are discussed. The crystallographic behavior of dust particles under elevated pressure and temperature with respect to their corrosive influence is reviewed. Particles studied include clay, limestone, dolomite, cement, silicate, coke, quartz, Zn, Fe, Cu, iron oxide and hydroxide, lead carbonate and others. Data concerning a conducive environment for dust corrosion show this corrosion beginning in the fine structure of metallic surfaces and favored by any deviation from an atomically smooth surface. It is likely that very small particles of graphite lubricants also become corrosion dust particles through recrystallization. A convergence of corrosive and wear effects is shown by the fact that very small dust particles adhere to metallic surfaces by sorption involving the hydrogen

bond. The breaking away of such particles leaves a series of small craters and this renders the surface susceptible to corrosion.

13. Gamma-Ferric Oxide ($\gamma\text{-Fe}_2\text{O}_3$) and the Passivity of Iron. M. C. Bloom and L. Goldenberg. Corrosion Science, v. 5, 1965, pp. 623-630.

In the past few years a large amount of evidence has been obtained indicating that passivity in the system $\text{Fe-O-H}_2\text{O}$ at room temperature is associated with the presence of a thin protective film having a modified form of the spinel structure of magnetite (Fe_3O_4). It seems to have been fairly well established that this protective film comprises two layers, namely a conductive film usually specified as Fe_3O_4 , in direct contact with the unoxidized metal, covered in turn by an electrically insulating film of what has been called " $\gamma\text{-Fe}_2\text{O}_3$." This $\gamma\text{-Fe}_2\text{O}_3$ has been visualized as a spinel structure containing vacancies.

In this study, the authors have brought together and correlated a substantial mass of existing data. The results of the study led to the conclusion that such protective films cannot be merely spinel structures containing vacancies but are modifications of the Fe_3O_4 structure in which protons are substituted for some of the ferrous iron and that $\gamma\text{-Fe}_2\text{O}_3$ is the end result of such a substitution when all ferrous iron has disappeared.

14. Materials Deterioration and Air Pollution. J. B. Upham. J. Air Pollution Control Association, v. 15, No. 6, June 1965, p. 265.

The present status of the Public Health Service program to assess the degradation of air pollution on materials is outlined. Dealing essentially with atmospheric corrosion, four major individual studies are described. These include the Five-Year, Eight City Corrosion Program, a project to study the relationship between air pollution and the atmospheric corrosion behavior of several metals in a number of selected American cities; and three small studies in St. Louis-East St. Louis metropolitan area; Chicago, Illinois; and Birmingham, Alabama. These latter three are of shorter exposure duration (one or two years) and are calculated to give a corrosion fingerprint of each area. Also discussed is a cotton textile exposure program being carried out in St. Louis in cooperation with the United States Department of Agriculture. For each study, objectives, methodology, and preliminary data are presented.

15. Significance of Corrosion Testing Process With Special Consideration of the SO_2 Test According to DIN 50018. W. Kesternich. Werkst. Korrosion, v. 16, 1965, pp. 193-201 (German).*

In condensed water with the addition of SO_2 (DIN 50018), steel corrosion increased as opposed to pure condensed water. Metals such as Cd, Ni, and Zn were corroded as much, in an SO_2 -containing atmosphere as low-alloy steels. Cd shows poorer results in corrosion than Zn and Ni; Sn, Al, and Cu show much better results. Data are given for the evaluation of corrosion testing and weathering experiments.

16. Systematic Corrosion Tests with Galvanic Coatings in a Sulfur Dioxide Atmosphere. A. Kutzelnigg. *Werkst. Korros.*, v. 16, No. 9, 1965, pp. 750-754.

The change in weight in the Testor apparatus with a SO₂ atmosphere in 1, 3, and 5 cycles was determined for sheet steel coated with Ni, Zn, and Cd and for bare sheet steel. Experimental conditions were varied. Additions of CO₂ and variation of temperature over the range 40-50° C had little effect on the results. Periods of drying at room temperature were without significant effect. The most essential factor was the amount of SO₂ supplied. Since the attack is quite strong on nickel with the usual SO₂ concentration (0.66 vol-pct), nickel coatings should be compared at 1 to 10 pct. of this concentration. The usual addition of SO₂ (2 liter) was maintained with the other coatings. Unprotected steel rusted 6-9 times as fast as nickel-coated steel.

17. The Effect of Initial Conditions of Exposure on the Subsequent Corrosion of Mild Steel. B. Sanyal, G. K. Singhania and V. K. Nigam. *Labdev.*, v. 3, No. 2, 1965, pp. 104-106.

Mild steel panels were degreased with S-free toluene and methyl alcohol and were dried and kept in a desiccator for 24 hours before exposure. The panels were exposed to air containing 0.33, 0.50, 1.0, 1.5, and 2.0 percent by volume SO₂ at 10, 20, 30, 40, 50, 60, 70, 80, 89, and 94 percent relative humidity for periods of 5 minutes to 24 hours. They were then transferred to pollution-free humid air. Corrosion during exposure for short periods in SO₂ atmosphere was negligible, but became severe when exposed to humid air. There was a decrease in corrosion rate when the exposed panels were kept in a desiccator for 8 hours or exposed to a stream of nitrogen or air at 40 and 80° prior to exposure over H₂O. The probable mechanism of corrosion involves the adsorption of SO₂ on the metal surface and the formation of a primary reaction film during pre-exposure and the formation of the final corrosion product due to hydrolytic reaction during the subsequent exposure over H₂O.

18. The Influence of Corrosion Products on the Progress of Atmospheric Corrosion. K. Barton and D. Knotkova-Cermakova. *Korrosion*, No. 17, 1965, pp. 53-57 (German).**

A general theory on the kinetics of long-range atmospheric corrosion is evolved from research data and the practical applicability of obtained results is suggested. A literature review covers qualitative works, the electrochemistry of atmospheric corrosion, the chemical reaction of atmospheric impurities, the effect of hygroscopic properties of solid corrosion products, quantitative experiments in long-range atmospheric corrosion, classification of partial reactions in atmospheric corrosion, formation of the electrolyte film, destruction of the primary oxide film, reactions of the formation of solid products, corrosion in the presence of solid corrosion products, the stationary state in atmospheric corrosion, improvement of the atmospheric corrosion resistance of steel, corrosion protection of rusted steel surfaces, and accelerated corrosion-testing methods.

19. The Rate of Corrosion of Carbon Steels in Land, Marine, and Industrial Atmospheres. E. Brauns and U. Kalla. Korrosion, No. 17, 1965, pp. 81-86 (German).**

The oxidation rate of various melted rimming, Si- and Al-killed ship plate steels with 0.05 to 0.20% C and traces of other alloying elements was investigated in land, marine, and industrial atmospheres. Results were obtained in 7-year exposures. In addition to the known effect of Cu, the mode of deoxidation had an explicit influence on corrosion resistance. Si-killed steels exhibited a distinctly lower oxidation rate in marine and particularly in industrial atmospheres than steels with identical or somewhat higher Cu content. After an approximate 5-year exposure, the corrosion process became stationary for all steels under investigation. Specimens brushed with a fiber brush prior to weighing showed the same corrosion behavior as those prepared by acid pickling with the addition of inhibitors, although considerable scale remained in the first case. After the sixth and seventh years, the oxide layers had the same weight and thickness regardless of the corrosion rate and atmosphere.

20. The Significance of Sulfur Dioxide in the Atmospheric Corrosion of Metals. G. Schikorr. Korrosion, No. 17, 1965, pp. 27-34 (German).**

The effect of SO₂ content on atmospheric corrosion in land areas is discussed and the relationship with local conditions and seasonal factors is reviewed. In the atmospheric corrosion of Zn a SO₂ content of 1.1 g/m² per day corresponds to a corrosion rate of 0.07 g/m² per day and results generally in the formation of ZnSO₄. In summer the corrosion products contain zinc oxides and basic zinc carbonates. A similar effect is valid for Cd and Ni. Cu and Pb presumably form a protective layer of basic sulfates and Al is somewhat protected by its oxide film. SO₂-affected corrosion of Fe in the atmosphere has three stages: the uptake of SO₂ by the rusty Fe, the formation of Fe(II) sulfate and the oxidation of the sulfate to rust and free sulfuric acid, the latter having a continuous corroding effect. The continuing corrosion is strongly dependent on temperature and relative humidity.

21. The Rusting of Low Alloy Steels in the Atmosphere. J. B. Horton. San Francisco Regional Technical Meeting of the American Iron and Steel Institute, San Francisco, CA, November 18, 1965, pub. as Regional Technical Meeting, American Iron and Steel Institute, pp. 171-195.

In complex corrosion-resistant, low-alloy steels, the order of effectiveness of alloying elements for improving atmospheric corrosion resistance are P, Cu (up to 0.3 percent), Cr, Si, and Ni. Copper above 0.3 percent and manganese have little effect. Sulfur is harmful. Examination of 17 year-old rust layers on low-alloy steel by X-ray diffraction, spectrographic, and chemical analysis did not explain how alloying elements improve atmospheric corrosion resistance. The rust layers are primarily α - and γ -FeOOH containing atmospheric dusts as well as sulfate, carbonate, and carbon. They also contain significant amounts of alloying elements from the corroded steel. The rust layers were found to have an outer layer in which the rust has enveloped atmospheric dust

and an inner layer free of such dust. The rust layers apparently grow by the diffusion of iron ions outward through the rust layer to precipitate as rust at the air interface, enveloping dusts within the fresh rust. Periodic wetting and drying of rust layers may vary where rust formation occurs in the rust layer, and thereby contribute to forming rust layers which are more impermeable to corrodants.

22. Theoretical Interpretation of the Ferrous(II) Sulfate Concentrations in Atmospheric Corrosion. H. Schwartz. *Werkst. Korros.*, v. 16, No. 3, 1965, pp. 208-212 (German).

Rust eruptions from atmospheric corrosion involve the electrolytic separation of $\text{FeSO}_4 \cdot x\text{H}_2\text{O}$ on anodic corrosion elements. Electrical condition of iron oxides plays an important role in the corrosion process. At the cathodic element, $\text{FeSO}_4 \cdot x\text{H}_2\text{O}$ reacts with OH^- (formed by the reaction: $2e + 1/2\text{O}_2 + \text{H}_2\text{O} = 2\text{OH}^-$), to produce Fe hydroxyl compounds that are oxidized to FeOOH .

1964

1. Atmospheric Corrosion of Steels Related to Meteorological Factors in Japan. I. Meteorological Factors in Japan. K. Oma, T. Sugano, T. Ueki and Y. Hirai. *Boshoku Gijutsu*, v. 13, No. 1, 1964, pp. 15-22 (Japanese).

Atmospheric corrosion rates of steels were measured every month between April 1962 and March 1963 at 19 typical districts in Japan selected from a meteorological viewpoint. The averages were as follows: industrial districts 55.3, Pacific coastal districts 20.4, Japan Sea coastal districts 18.8, and inland districts 5.1 mg/day-dm². Among the selected factors such as temperature, humidity, precipitation, etc., the temperature effect was most important to the atmospheric corrosion of steels, even though SO_2 and Cl ions could sometimes become decisive in conjunction with meteorological factors.

2. Corrosion of Iron and Steel in NH_4NO_3 -- NH_3 -- H_2O Solutions. G. Schick and H. H. Uhlig. *J. Electrochem Soc.*, v. 111, No. 11, 1964, pp. 1211-1215.

Iron corrodes in aqueous NH_4NO_3 -- NH_3 solutions at high rates (>2 in. per year) depending on NH_3 concentration and on certain metallurgical factors. The corrosion product, by analysis, is found to be $[\text{Fe}(\text{NH}_3)_6](\text{NO}_3)_2$ in the presence of NH_3 , and Fe_3O_4 in its absence. Cold-rolled iron corrodes more rapidly than annealed or quenched iron. The cause is related to orientation during rolling of the (001) face of iron parallel to the surface. This face is one that apparently corrodes most rapidly. Orientation is partially destroyed by annealing or quenching. Such effects are marked only when rate of complex formation is controlling; when other reactions control, the effect of cold work is not pronounced. The corrosion rate is sensitive to alloyed N but not to

alloyed C. Zone-refined iron corrodes at a rate comparable to that of annealed mild steel. Iron containing 0.04 percent N corrodes at a lower rate or about 1/4 that of zone-refined iron. Inhibitors such as SCN appear to interfere with the cathodic reduction of NO_3 to NH_3 .

3. Investigation of Atmospheric Corrosion Behavior of Selected Nickel Alloys. H. R. Copson and E. A. Tice. *Werkst. Korros.*, v. 15, No. 8, August 1964, pp. 642-652 (German).

Data collected in exposure tests for 23 years in industrial atmosphere of Bayonne, N.J. and 15 years in marine atmosphere of Kure Beach, N.C., are presented and discussed. Metals exposed include commercial Ni, Ni-Cu and Ni-Cr alloys, precipitation hardenable stainless steels, wrought ferrous alloys with 3 to 80 percent nickel, cast iron with 35 percent nickel, copper- and manganese-base alloys, and others.

4. The Influence of Sulphur Dioxide on the Atmospheric Corrosion of Metals. G. Schikorr. *Werkst. Korros.*, v. 15, No. 5, 1964, pp. 457-463.

The paper provides a synopsis of present-day knowledge of the subject. With zinc, nickel and cadmium, the atmospheric corrosion is roughly equivalent to the quantity of SO_2 absorbed from the air, and sulphates are formed. Low air humidity reduces the absorption of SO_2 , and thus the corrosion of these metals. With iron, on the other hand, a simple mechanism causes the sulphur dioxide to have a catalytic effect, and oxides are formed. A high relative humidity of the air promotes these processes; a low humidity reduces them but does not affect the SO_2 absorption. Due to the formation of protective layers containing sulphates, lead and copper have a particularly high weather resistance. The high weather resistance of aluminum is due to protective layers of aluminum oxides and their low capacity of absorbing SO_2 .

1963

1. Atmospheric Corrosion. R. K. Swandby. *Corrosion Resistance of Metals and Alloys*, edited by F. L. Laque and H. R. Copson, Reinhold Publishing, New York, 2nd edition, 1963, pp. 45-47.

Humidity and oxygen are the basic corrosive agents of the atmosphere. In addition, sulfur compounds in form of hydrogen sulfide or sulfur dioxide are the most active in industrial atmospheres. Chlorides are more corrosive than sulfur compounds in marine atmospheres.

2. Atmospheric Exposure of Aluminum Alloys for Three Years in Nigeria. K. G. Latimer and F. F. Booth. *Metallurgia*, v. 67, 1963, pp. 73-79.

Atmospheric exposure tests were made at marine, desert, town and jungle sites. Specimens in a wide range of Al alloys, Al-Mn, Al-Mg, Al-Mg-Si, Al-Cu, and Al-Zn-Mg in the form of sheet and angle were exposed

together with mild steel and galvanized mild steel. The examination dealt with appearance, tensile properties, and depth of attack after 1, 2, and 3 years. Tropical atmospheres which are not heavily polluted are no more corrosive to aluminum than temperate ones. Aluminum is much superior to mild steel and galvanized mild steel. The Nb alloy containing 5 percent magnesium is prone to grain-boundary pptn. of the β -phase after tropical exposure. This indicates susceptibility to stress corrosion. A simple zinc chromate paint has a satisfactory life in a tropical marine atmosphere.

3. Corrosion Resistance of Cast Irons. H. H. Collins. BCIRA J., v. 11, No. 5, Sept. 1963, pp. 589-595.

This paper reviews work carried out on comparative corrosion rates and resistance of various cast irons to soil, seawater, acids and alkalis, and atmospheric corrosion.

4. Influence of Atmospheric Contaminants on Corrosion - Literature Report. H. C. Muffley. DDC Report AD-420118, Rock Island Arsenal, Ill., June 13, 1963, 23 pp.

The influence of atmospheric contaminant gases and particulate matter upon the corrosion rates of ferrous and nonferrous metals is investigated. Various means of protection from, or elimination of, such corrosive environments are reviewed. Variations in the rate of corrosion coincide with the severity of atmospheric pollution in different locations where average humidity is approximately the same. Because of this interaction of the various pollutants and moisture, and the fact that these vary independently, it is difficult to predict the corrosion behavior of a location. It has been observed that the corrosiveness of a given atmosphere is not constant, but varies with the weather conditions. Some areas will show a difference in the corrosion of specimens put out at different seasons of the year. Data from the tests in both industrial and marine atmospheres, reveal that very great difference in corrosivity can exist at locations only a few miles apart, or, in some extreme cases, only a few 100 feet apart. The corrosion rates of various metals or alloys for various environmental conditions are given. Corrosion of metals can be overcome 1) by eliminating the contaminants that cause corrosion of metal parts, 2) by preventing the contaminants from coming in contact with the metal surface, and 3) by using a metal finish that will be resistant to the specific atmosphere.

5. Mechanism of the Atmospheric Corrosion of Iron. G. Schikorr. Werkst. Korros., v. 14, No. 2, February 1963, pp. 69-80.

The mechanism of atmospheric corrosion of iron involves the following steps: adsorption of SO_2 by iron (no corrosion in this step),
 $\text{Fe} + \text{SO}_2 + \text{O}_2 = \text{FeSO}_4$, $4 \text{FeSO}_4 + \text{O}_2 + 6 \text{H}_2\text{O} = 4 \text{FeOOH} + 4 \text{H}_2\text{SO}_4$, and $4 \text{H}_2\text{SO}_4 + 4 \text{Fe} + 2 \text{O}_2 = 4 \text{FeSO}_4 + 4 \text{H}_2\text{O}$.

6. Remote Protection Effect of Zinc and Cadmium for Steel Exposed to the Atmosphere. G. Schikorr. Galvanotechnik, v. 54, No. 3, 1963, pp. 122-126.

Steel rods, zinc or cadmium coated, were wound with an iron wire and exposed to atmospheric conditions and SO₂- and acetic acid-containing media. Weight losses of the iron wire were tabulated for the various conditions. Scratch tests were applied in the SO₂ atmosphere whereas plots of i versus acetic acid concentration were used for the acid atmosphere. These tests can also be used to determine porosity in electrodeposits of zinc and cadmium.

7. What Price Maintenance-Free Structures? J. C. Pohlman. Electrical World, v. 159, 1963, pp. 72-74.

Traditionally, transmission towers and substation structures have been made from galvanized steel. After the galvanized coating has weathered away, it is customary to paint the structure to maintain the integrity of the base metal. The increase of painting costs has spurred engineers to consider "maintenance-free" materials. The question then arises: How much premium can be justified for the "maintenance-free" structure to eliminate painting?

1962

1. Aluminum Alloys Corrosion Behavior in an Industrial Environment. F. F. Booth and K. G. Latimer. Corrosion Technology, v. 9, No. 11, 1962, pp. 315-320.

In 1948, as part of a comprehensive long-term investigation of the corrosion resistance of aluminum alloys, atmospheric exposure tests were undertaken by Aluminum Laboratories Ltd., Banbury, at a number of corrosion sites. This paper deals with the examination of strips cut at various times from sheet panels that were exposed in an industrial area at Stratford, London. The panels included most of the standard production aluminum alloys, mild steel, galvanized steel, and 18-8 stainless steel.

2. Atmospheric Corrosion by Electrolyte Nuclei. B. Sanyal and D. V. Bhadwar. J. Sci. Industr. Res., v. 21D, 1962, p. 243.

The atmospheric corrosion of mild steel, aluminum, copper, zinc, brass, tinsplate, galvanized iron and lead, representing common engineering metals, by nuclei of selected electrolytes representing the corrosive constituents of metal treatment materials likely to be left as residues on metal surfaces has been investigated under controlled conditions. A new technique has been developed for innoculating the metal surfaces with the electrolyte nuclei which consists in depositing a definite quantity of the electrolyte on the metal surface by immersing metal specimens in aqueous solutions of the electrolytes for a few seconds and drying in vacuum and at 100° C. The corrosion rates of the different metals have been, in

general, found to be in the following descending order: mild steel, galvanized iron, zinc, copper, brass, tinplate, lead, aluminum; of these metals, only the first four undergo appreciable corrosion. The chlorides are more corrosive than the sulphates. Corrosion rates increase with increase in humidity, temperature, period of exposure and concentration of electrolyte on the metal surface. Corrosion is also influenced by the pH of the solution used for inoculating the metal surfaces. In the case of mixtures of electrolytes, the corrosive effect of one electrolyte is not influenced by the presence of other electrolytes and the total effect is additive. Corrosion under immersed conditions is much lower than that due to atmospheric corrosion by nuclei of electrolytes, but aeration of the electrolyte solution under immersed condition causes a rapid increase in the rate of corrosion, which finally approaches that under atmospheric exposure.

3. Atmospheric Corrosion of Metals. Some Questions of Theory.

I. L. Rosenfel'd. Proc. 1st Intern. Congr. on Metallic Corrosion, London (1961), Butterworth, London, 1962, pp. 243-248.

The paper describes the electrochemical methods of investigation that have been developed for studying atmospheric corrosion in thin electrolyte layers. Some theoretical aspects of atmospheric corrosion, resulting from the data obtained, with the aid of the methods mentioned, are considered and some new views on atmospheric corrosion mechanisms are suggested.

The rate of oxygen depolarization in thin electrolyte layers beginning with $h = 3 \times 10^{-2}$ cm increases according to the hyperbolic law. The dependence of the oxygen reduction rate on the thickness of the diffusion layer is determined by the equation $i\delta = 0.190 \times 10^{-5}$. In the case of many industrial metals (iron, steel, zinc, magnesium) the anodic reaction of metal ionization proceeds very slowly in thin layers. The oxygen depolarization rate increases markedly in the course of electrolyte evaporation from the metal surface. Owing to the surface-tension changes, thin electrolyte layers self-mix and exhibit convection oxygen transfer. The thickness of the diffusion layer in thin films is much below the values assumed for such layers when relatively large electrolyte volumes with natural convection are considered. Under thermostat controlled conditions ($\pm 0.05^\circ$) $\delta = 3$ to 15×10^{-3} cm. The work of microcells in thin electrolyte layers is controlled by polarization, and not by resistance. The basic controlling factor is the cathodic process (70-90 percent). Thin electrolyte layers show a change in current distribution in the direction of the growth of current density at the interface. The equation of current density distribution is given. A new kind of cathodic depolarization has been observed which is due to the reaction of sulphur dioxide reduction. The mechanism of enhancement of metal corrosion in industrial districts polluted with sulphur dioxide is associated with this reaction.

4. Corrosion of Metals in an Atmosphere of Sulfur Dioxide. V. G. Gleim, G. F. Potemkin, E. M. Lavrova and S. G. Tereshchenko. Tr. Vses. Mezhvuz. Nauchn. Konf. po Vopr. Bor'by s Koroziiei, Azerb. Inst. Nefti i Khim., 1962, pp. 287-290 (Russian).

The corrosion of cast iron and bronze, dry or coated with diesel oil, in 5 and 100 percent SO_2 , with and without additions of 5, 10, and 20 percent NH_3 was investigated at 20° and 500°. The gain in weight over 6 hours was determined by approximately hourly weighings. Similar determinations were made in a special apparatus with diesel exhaust gases, with and without additions of SO_2 and NH_3 . Results are presented as curves showing weight gain in grams versus time in minutes (sample sizes are not shown). NH_3 lowers the corrosion in all cases, for example, by approximately 50 percent with cast iron covered with oil in 100 percent SO_2 and 20 percent NH_3 during 300 minutes at 500°. Additional studies were made with silicone coatings. Best protection was obtained with lacquer FG-9 (a condensate of aryl-trialkoxysilanes) pigmented with aluminum powder. At 20° the lacquer lowered the corrosion of cast iron in 10-100 percent SO_2 by a factor of 13-15. At 600° the protection lasted for 10-12 hours. At 700° there was no protection, as lacquer burned off.

5. Corrosion of Steel. H. Greenblatt and R. Pearlman. Chemistry in Canada, 1962, p. 21.

The effects of some possible atmospheric contaminants on the corrosion of steel at three different humidities and temperatures were investigated in a series of simple laboratory tests. The trends observed confirm trends observed by different workers in outdoor exposures at different sites and indicate that there is complex interplay between the effects of contaminants, humidity and temperature.

6. Effects of Air Pollution on the Atmospheric Corrosion Behavior of Some Metals and Alloys. E. A. Tice. J. Air Pollution Control Assoc., v. 12, 1962, pp. 553-559.

The SO_2 content of the air, especially as found in industrial atmospheres, is the most significant constituent responsible for corrosion of metals such as steel and zinc and to a lesser extent, alloys containing copper and nickel. Chromium-nickel stainless steels resist corrosion by SO_2 , but darken owing to dirt and soot accumulations and are eventually attacked owing to the development by carbon of local galvanic corrosion cells which will perforate the material.

7. The Atmospheric Corrosion of Steels as Influenced by Changes in Chemical Composition. C. P. Larrabee and S. K. Coburn. Proc. 1st Intern. Congr. on Metallic Corrosion, London (1961), Butterworth, London, 1962, pp. 276-285.

The method used for testing steels in the atmosphere is described and the types and relative corrosivity of different atmospheres compared. The results of long-time-exposure tests are plotted to show the shapes of time-corrosion curves of steels with varying resistances.

The effect on corrosion resistance of steels having variations in chromium, copper, nickel, phosphorus and silicon is given for each element and when present in certain combinations. Data are taken from individual 15-year tests in industrial, semi-rural and marine atmospheres. Two hundred and seventy steels with three variations of chromium content, five of copper, two of nickel, three of phosphorus, and three of silicon were tested.

8. The Possibilities of Increasing the Resistance of Steel Against Atmospheric Corrosion. K. Barton. Intern. Symp. Anti-Corrosion Protect. Bratislava, v. 1, 1962, 8 pp.

Corrosion tests were made in aerated H₂O and in moist air with and without SO₂ on plain carbon steel, plain carbon steel coated with a cemented copper layer, copper-bearing steel, steel spray-coated with 0.03 mm zinc on prerusted surface, and steel spray coated with 0.03 mm aluminum on blasted or prerusted surface. Rust binds sulfates or chlorides in an insoluble form. The influence of alloys on corrosion resistance is based on the improvement of the protective properties of rust. Alloys can be simulated by thin porous coatings of zinc.

1961

1. Atmospheric Corrosion. S. Coburn. Metals Handbook, 8th edition, American Society for Metals, Chapt. in vol. 1 - Properties and Selection of Metals, 1961, pp. 717-723.

The atmospheric corrosion of carbon steels and high-strength, low-alloy steels is discussed. The effects of geographic and meteorological factors, dew, dust, shelter, and alloy composition are described. Data are presented for the corrosion of steels at different locations.

2. Atmospheric Corrosion. U. R. Evans. Chapt. 8 in The Corrosion and Oxidation of Metals, Edward Arnold, 1961, pp. 481-535.

Atmospheric corrosion was divided into three types, "dry", "damp", and "wet". The dry process, being related to high-temperature oxidation was discussed in another chapter. Some of the topics discussed in the "Damp Atmospheric Corrosion" section were: The critical humidity, the effect of volatile acids and alkalis (sulphuric acid, hydrochloric acid, sulphur dioxide, ammonia, etc.) on the damp corrosion of metals, the fogging of nickel, the attack on copper by air containing SO₂ and moisture, the influence of dust on rusting. Some of the topics discussed in the "Wet Atmosphere Corrosion" section were: effect of air pollution on outdoor corrosion, effect of copper in steel. A comparison study was made of the corrosion resistance of different materials. Different methods for the protection of metals were cited.

3. Atmospheric Corrosion Testing of Metals in Canada. E. V. Gibbons. Corrosion, v. 17, 1961, p. 318t.

The atmospheric corrosion resistance of metals is evaluated after exposure in a number of differing Canadian environments. Test sites included rural, industrial, marine-industrial, marine, far northern and semi-industrial. Metals exposed include three aluminum alloys, aluminum coupled metals, carbon steel, copper-bearing low carbon steel, low alloy copper-nickel-bearing steel, three stainless steels, two magnesium alloys, and rolled zinc. Test exposure periods varied from one to ten years.

4. Atmospheric Corrosion Tests of Electroplated Coatings. T. Biestek. Prace Inst. Mech. Procyzyjnej, v. 9, No. 31, 1961, pp. 39-49.

Corrosion tests were continued on the low-carbon steel panels covered with Zn, Cd, or Sn coatings 1 to 30 μm thick in industrial (a), urban (b), urban-industrial (c), seacoast-industrial (d), and rural (e) atmospheres in Poland. The average rates of corrosion of zinc coatings, electroplated from a cyanide or an acid bath, were in (a) 4.5, 6.3; (b) 2, 3.5; (c) 1.3, 2.6; (d) 1.2, 1.8; (e) 0.9, 1.6; and under severe storage conditions 0.6, 0.8 microns/yr, respectively. Zinc coatings deposited from an alkaline cyanide bath were more resistant than those from an acid bath, which was attributed to a less uniform and compact structure of the latter. Cadmium coatings corroded 2 to 3 times as fast as zinc coatings. Tin coatings were least resistant. A series of new corrosion tests was started on Cr-, Ni-, Cu-Ni-Cr-, and Zn-Cr- coated steel panels.

5. Corrosion in Buildings. P. J. Sereda. Canadian Building Digest. Report No. CBD-20, August 1961, 4 pp.

The document covers the susceptibility of metals used in building construction to various types of corrosion and discusses possible measures to reduce or eliminate corrosion.

6. Effect of Nitrogen Tetroxide on Metals and Plastics. C. W. Alley, A. W. Hayford and H. F. Scott, Jr. Corrosion, v. 17, No. 10, October 1961, pp. 479t-484t.

The corrosion rates of carbon steel, stainless steel (304-L and PH 15-7 Mo), Al (5086) and Ti (75A and 6Al4V) in dry and wet N_2O_4 were determined under static conditions at 9 to 74° C. Carbon steel and aluminum were attacked in proportion to water concentration and temperature. Stainless steel 304-L and titanium were unattacked and PH 15-7 molybdenum only slightly attacked. Significant corrosion of stainless steel (304L) occurred in the presence of Teflon. Corrosion by dry N_2O_4 under flow conditions was negligible. Teflon was the most resistant to N_2O_4 of any of the plastics.

7. Some Aspects of the Topochemistry of the Iron Oxides and Hydroxides.
A. L. MacKay. Proc. 4th Intern. Symp. Reactivity Solids, Amsterdam, Holland, 1961, pp. 571-583.

The crystal structures of the iron oxides and hydroxides are now largely known. β -FeOOH has been shown to have the α -MnO₂ structure and some proposals are made for the structure of the "green rusts"--the intermediate ferrous ferric hydroxysalts which are formed on the attempted precipitation of Fe(OH)₂ in the presence of air. Details of the superstructures in the γ -Fe₂O₃ and other spinel phases are still incomplete but some progress has been made in this direction too. The data now permit the organization of the observations on the oriented and non-oriented transformations occurring between the solid phases in this system in a rational crystal-chemical way. Almost all of these transformations involve the gain or loss of material to the system and are thus not simply polymorphic. A number of new observations by X-ray diffraction, electron diffraction and electron microscopy are reported. These (and other) transformations can be classified as "topotactic" (accord between the initial and resulting lattices in three dimensions), "epitactic" (accord in two dimensions) or "reconstructive" (regrowth from nuclei), the latter process also occurring by solution and reprecipitation. Some examples of these processes are described in detail. Crystals undergoing topotactic transformations obey certain orientation requirements which may be modified by the application of an external field.

In the system studied, the controlling features appear to be the close-packed oxygen frameworks in the interstices of which the relatively mobile iron ions can migrate. The expulsion of water and the condensation of new layers permit some change in the layer stacking, but otherwise the hexagonal close-packed, face-centered cubic and body centered cubic stackings are not readily interconvertible. The mobility of protons in the lattice plays a vital part in permitting a surface reaction to result in a homogeneous solid product. Various disordered phases are described and some physical consequences of the disordering are discussed. The scheme of transformations in this system is summarized in a chart organized to show crystal-chemical properties.

1960

1. Atmospheric Factors Affecting the Corrosion of Steel. P. J. Sereda. Ind. Eng. Chem., v. 52, No. 2, 1960, pp. 157-160.

Measurement of temperature, sulfur dioxide, and surface moisture has resulted in systematic evaluation of the atmospheric corrosion of steel and should provide a basis for the rating of inland exposure sites.

2. Atmospheric Corrosion of Iron and Steel. T. Berglund.
Teknisk-Vetenskaplig Forskning, v. 31, No. 8, 1960, pp. 325-348.*

At Sandviken, Sweden, outdoor corrosion is caused by air humidity (average temp. 5°, average wind speed 2.7 m/sec.) 33%, Fe₂O₃, C,

SiO₂, etc., 4%, natural Cl content in air as NaCl, etc., 0.04%, the rest 63%. The unspecified rest is probably SO₂ and traces of pickling liquors.

3. Chemical Resistance to Ammonia of Construction Materials.

A. E. Missan. Trudy Gosudarst. Inst. Priklad. Khim., v. 44, 1960, pp. 112-127 (Russian).

Tests were made at 16 to 18° and 50° at the equilibrium vapor pressure of NH₃. The NH₃ contained <0.038-0.041 percent moisture. The following materials were completely resistant to liquid and gaseous NH₃ up to 50°: steels 25, 45, 30KhGSA, 50KhFA, 2Kh13, 1Kh18N9T, 2Kh18N0, Kh18, 4Kh13, 4Kh14N14V2M; Ni; and Monel. These results are confirmed by literature data. The following metals are corroded uniformly at <0.3 g/sq m/hr in both liquid and gaseous NH₃ at both 16 to 18° and 50°: copper M3, bronzes Be (BrB2-2-15), Pb-P (BrOF7-012), Al-Fe-Mn (BrAZhMts10-3-1.5), SnPb (BrOS5-25), and regular bronze (BrKh1). With brass the elimination of zinc was observed. Zinc and cadmium coatings are unstable under the above mentioned conditions, while chromium coatings show good stability. Aluminum and aluminum alloys show pitting corrosion when the iron content exceeds 0.15 percent. High-purity Al AV1 (Cu 0.005, Si 0.050, Fe 0.060 percent) and A00 (Cu <0.01, Si 0.10, Fe 0.15 percent) do not undergo corrosion in NH₃. Less pure aluminum grades show pitting and considerably more so in liquid NH₃ than in gaseous. Anodizing of aluminum does not protect against corrosion in NH₃. All the above mentioned metals which undergo corrosion in NH₃ show less corrosion when their surfaces are cleaned more thoroughly.

4. Evaporated Metal Films As Indicators of Atmospheric Pollution.

J. P. Lodge, Jr. and B. R. Havlik. Int. J. Air Pollution, v. 3, No. 4, 1960, pp. 249-252.

A substitute is proposed for present techniques of measuring atmospheric corrosiveness, namely the use of evaporated metal films a few hundredths of a micron in thickness. Glass slides covered with films of aluminium, iron, lead, copper and silver were prepared and exposed in the Cincinnati area.

Corrosion products were identified by means of X-ray diffraction and microchemical methods. Corrosion results in an increase in light transmission by the film, which can be taken as a quantitative measure of corrosion. Preliminary results showed aluminum to be the most dependable indicator of general atmospheric corrosiveness, although silver appeared specifically sensitive to a small group of pollutants, such as halogens, ozone, and sulfur compounds. Lead corroded so rapidly as to be difficult to interpret while iron was shown to be responsive primarily to relative humidity. Fair correlations were obtained with independent measures of pollution level. Some exploratory work was done on the measurement of the electrical resistance of the films.

5. Long-Time Atmospheric Corrosion Tests on Low-Alloy Steels. H. R. Copson. Proc. American Society for Testing and Materials, v. 60, 1960, pp. 650-665.

Atmospheric corrosion test data are given for a large group of low-alloy steels through 15.5 years at a marine location at Kure Beach, N.C., through 17 years at a marine location at Block Island, R.I., and through 18 years at an industrial location at Bayonne, N.J. In the absence of alloying elements, corrosion was severe and early failure resulted. Alloying with copper, phosphorus, nickel, and chromium was beneficial. Such low-alloy steels quickly developed protective rust coatings, and the corrosion rates decreased rapidly to low values. During the last half of the test periods the corrosion rates of many of the better low-alloy steels ranged from 0.05 to 0.2 mil per year, with the higher rates applying to the marine locations. The durability of bare, reasonably thick, boldly exposed specimens of good low-alloy steels is remarkable.

6. The Atmospheric Corrosion Product of Steel. J. B. Harrison and T. C. K. Tickle. Chem. & Ind. (London), 1960, p. 1383.

Structural steel after atmospheric exposure had a comparatively high SO_4^{2-} and Cl^- content in its adherent rust. The debris removed by wire brushing contained all of the Cl^- contamination, but only a small portion of the SO_4^{2-} contamination. Digestion in diluted HCl of the wire-brushed surface gave a solution containing the remainder of the SO_4^{2-} contamination, with a surprisingly high NH_4^+ content. The generation of firmly bound NH_4^+ contamination on the surface of the corroding steel was rapid and soon reached 0.01 g/sq.ft. This rate was not changed markedly with continued exposure. Mill-scaled steel, as received and before exposure, had an appreciable NH_4^+ content. Thus, it is believed that a determining factor, controlling the atmospheric corrosion of steel and the subsequent behavior of surface coatings, was a contribution of NH_4^+ -induced corrosion.

7. Theory of Atmospheric Corrosion of Metals. N. D. Tomashov. Trudy Inst. Fiz.-Khim., Akad. Nauk S.S.S.R., No. 8, 1960, pp. 14-40 (Russian).*

The following three types of atmospheric corrosion of metals are distinguished: (1) wet atmospheric corrosion when dropwise condensation of moisture on the metal surface is visible with the naked eye; (2) humid atmospheric corrosion, when a very thin, invisible layer of moisture is present on the metal surface, being condensed on this surface owing to capillary, adsorption, or chemical action; and (3) dry atmospheric corrosion, when the metal surface is free of moisture. In practice one type of corrosion can go over into another. The rate of corrosion depends largely on the thickness of the moisture layer on the metal surface. With a very thin (10-100 Å; not yet continuous) film of moisture, the rate of corrosion is not much different from that of dry corrosion, that is, the corrosive action has a purely chemical character. With increased thickness (1 micron) of the moisture film, the rate of corrosion starts to increase rapidly, because the film starts to act as an electrolyte and the corrosive action assumes electrochemical character. The latter

effects take place in the humid atmospheric corrosion range. After reaching a maximum, the rate of corrosion starts to drop with a further increase in film thickness (when a visible moisture layer is present on the metal surface (thickness about 1 mm); this is the range of wet atmospheric corrosion. Finally, when corroded metal is immersed in the electrolyte (water), the corrosion assumes a constant rate. Critical values of relative humidity were determined, at which corrosion rates rise sharply. These values for copper and iron are as follows: for a copper surface which was previously corroded in pure air, 87 percent; for a copper surface which was previously treated with gaseous SO_2 , 80 percent; for a copper surface which was previously treated with iodine vapor, 30 to 40 percent; for a clean iron surface in pure air, approximately 100 percent; for an iron surface which was previously corroded in 3 percent NaCl , 55 percent. Passive iron will not corrode even at 100 percent relative humidity, except when Cl^- , SO_2 , or other activating agents are present. Experiments by Tomashov and others on corrosion rates, on models on electrochemical characteristics of Cu, Zn, Fe, and Al surfaces covered with an adsorption film of moisture, and on the protective effect of copper on iron corrosion are reviewed.

1959

1. Atmospheric Corrosion of Steel. P. J. Sereda. Ind. Eng. Chem., v. 51, No. 9, 1959, pp. 79A-80A.*

The following equation is developed for low-C steel: $Y = 0.1315X + 0.0180Z + 0.7873$, where Y = the log corrosion rate (mg/sq dm/day of wetness), X = mg SO_3 /sq dm/day and Z = monthly average temperature during the time-of-wetness ($^{\circ}\text{F}$).

2. Atmospheric Corrosion Tests. J. C. Hudson. Sixth Report of the Corrosion Committee, Iron and Steel Institute, 1959, pp. 48-103.

The presentation of the results of the Corrosion Committee's earliest series of field tests on the atmospheric corrosion of structural irons and steels is completed. Tests were made on more than twenty different materials, many of which were exposed in both the bare and painted conditions. Some information about the meteorological conditions and atmospheric pollution at the test sites is given. The main results of some service trials of painting schemes that were applied to the iron and steel exposure stands are also contained.

3. Corrosion of Metals in Synthetic Atmospheres Containing Sulfur Dioxide. B. Sanyal and D. V. Bhadwar. J. Sci. and Ind. Research (India), v. 18A, February 1959, pp. 69-74.

The purpose of the experiments was to investigate the resistance of mild steel, Cu, Zn, and Al sheets (and galvanic couples) to atmospheric corrosion under controlled laboratory conditions of relative humidity, concentration of SO_2 , temperature, and duration of exposure. When the

concentration of SO_2 is 0.3 percent, aluminum and mild steel required 80 percent and 65 percent relative humidity, respectively, for corrosion to begin. For copper and zinc corrosion begins at 40 percent relative humidity (the lowest concentration tested). At 89 percent relative humidity, corrosion increases with the concentration of SO_2 . Rise in temperature increases the corrosion rate up to a maximum beyond which, due to lower solubility of SO_2 in water vapor, it decreases. Couples of various metals were also tested.

4. Design and Interpretation of Atmospheric Corrosion Tests. H. R. Copson. Corrosion, v. 15, No. 10, October 1959, pp. 533t-541t.

Principles under which atmospheric corrosion tests are made are much the same as those applicable to other types of testing. Considered, among other things are uses of accelerated tests, specimen size, location of test sites, differences in atmospheres, differences in metals and influence of alloying constituents.

Mounting procedures, shape of specimens, drainage, influence of rainfall, influence of climatic variations, uses of shelters reproducibility, test duration, evaluation of results are discussed.

5. Deterioration of Materials in Polluted Atmospheres. J. E. Yocum. Corrosion, v. 15, No. 10, October 1959, pp. 541t-545t.

A brief summary of the chemical and physical aspects of polluted atmospheres is given. More specifically it deals with the detrimental effects of air pollutants on materials other than living tissue. In addition to corrosion of metallic surfaces, the physical and chemical principles involved in the damage to such materials as paint, glass, stone, rubber, and fibers by man-made air contaminants are discussed.

6. Mechanisms by Which Ferrous Metals Corrode in the Atmosphere. C. P. Larrabee. Corrosion, v. 15, No. 10, 1959, pp. 526t-529t.

The electrochemical theory of corrosion, by which the corrosion of steels in solutions is readily explained, also is used to explain the start of atmospheric corrosion on ferrous surfaces. Effect of contaminants both in the atmosphere and on the steel surface. Experiment Experiments leading to this conclusion are illustrated.

The part played by various alloying elements in retarding atmospheric corrosion, once a rust film is formed, is discussed. The relative effects of heavy and light deposits of sea salt on ferrous specimens are shown.

7. Reaction Mechanism for the Atmospheric Corrosion of Metals in Damp and Sulfur Dioxide-Containing Air. K. Barton and E. Beranek. Werkst. Korros., v. 10, 1959, pp. 377-383.

The rate of oxidation by H_2SO_3 (SO_2 0.3 g/l) was determined in ultraviolet light and in darkness, alone and with Cu, Cu^{++} , Fe,

Fe^{++} , Zn, and Zn^{++} . All corrosion experiments with moist SO_2 on Fe, Al, Cu, and Zn are strongly dependent on the SO_2 concentration. Corrosion is determined by concentration of H_2SO_3 and H_2SO_4 in the adsorbed water film, properties of solid and solution reaction products, rate and mechanism of reaction at metal surface, and the original resistance of the oxide layer on the metal.

8. Report of Sub-Committee VII, On Corrosiveness of Various Atmospheric Test Sites as Measured by Specimens of Steel and Zinc. Proc. American Society for Testing and Materials, v. 59, 1959, pp. 174-201.

Final report of the investigation into the effects of periodic variation in weather conditions on atmospheric corrosion shows, in some atmospheres, there are decided differences in relative corrosion rates of steel and zinc. At marine sites the rate of corrosion of zinc decreased with time whereas that of steel increased. At least three successive 2-year exposures may be necessary to obtain a relative corrosion index for zinc at different sites; 1 year's exposure alone is not enough, especially at marine sites. It is planned to expose a new series of specimens in 1960.

1958

1. A Polarographic Study of the Corrosion of Iron and Some Ferrous Alloys by Sulfur Dioxide. F. J. Bowen and A. H. Gropp. Corrosion, v. 14, 1958, p. 50.

A study was made of the manner in which sulfur dioxide attacks iron and ferrous alloys. A polarographic method was used to follow the changes in the sulfur dioxide concentration. Tests were made on one pure iron and seven low alloy steels exposed to sulfur dioxide over 12 hour periods. Extensive data are reported on the rate of consumption of sulfur dioxide by the various test samples. A corrosion mechanism involving the reduction of sulfurous acid by iron to give the sulfide is discussed.

2. Atmospheric Corrosion of Iron and the Action of Volatile Inhibitors. Z. A. Iofa. Vestnik Moskov. Univ., Ser. Mat. Mekhan., Astron., Fiz. Khim., v. 13, No. 5, 1958, pp. 171-180 (Russian).*

With a decrease in the humidity content of the air, in the region below a definite critical corrosion threshold, corrosion does not practically take place even in the presence of corrosive substances or oxygen. Contrary to humidity, oxygen is not an indispensable factor in atmospheric corrosion, since the corrosion of iron takes place very rapidly in an inert gas in the presence of corrosive substances (HCl and SO_2). In an oxygen-free atmosphere, corrosion is possible only through H depolarization, that is, in a reduction medium, and in that case the product of corrosion is the hydrated lower oxide of iron with the corresponding oxy-salts as impurities. When, in the initial period, the corrosion rate is relatively small and the absorption of the corrosive

substance by the humidity condensed on the surface takes place rapidly, it is possible to establish the relation between the amount of corrosive substance and iron in the rust formed. For example, in the presence of HI in the atmosphere, rusting does not take place during the first 1 to 2 hours, and the quantity of HI on the surface of iron increases. After 2 hours, over a solution of $N H_2SO_4 - 2.7 \times 10^{-8} N$ KI the thickness of the water film is equal to 0.5×10^{-4} cm and the concentration of HI in this film reaches 4N. In the case of gaseous HCl, the acid is apparently formed on the surface and this results in an intense corrosion of iron. Sulfur dioxide rapidly reacts with iron even at very small concentrations of H_2SO_4 in the humid film. FeS appears after 5 minutes when sulfur dioxide is present in the gaseous phase with a partial pressure of 0.2 mm Hg. The mechanism of the action of the different corrosive substances is quite varied; it is different even for the chemically-similar halogen acids. The degree of influence on the corrosion rate by the same inhibitor depends on the nature of the corrosive substance, particularly at the initial stage of its development. For example, amines are effective inhibitors against iron corrosion in the presence of HI, HBr, and especially sulfur dioxide in the gaseous state, but is much less effective in the case of HCl. Upon dissolving iron in H_2SO_4 , H_2S , and SO_2 in small amounts in the presence of nitrogen-containing organic bases (for example, tribenzylamine) not only lose their stimulating properties but increase the retarding action of the latter. Aldehydes (butyric and propionic) inhibit atmospheric corrosion in the presence of HX (X = halogen), although to a smaller degree than amines; however, in the presence of sulfur dioxide, they stimulate corrosion, even in H_2SO_4 . When volatile inhibitors capable of stifling the atmospheric corrosion of iron are present in the gaseous phase, the adsorption of the corrosive substance on the surface of the metal reasonably decreases.

3. Corrosivity of Atmospheric Precipitation Contaminated by Harmful Impurities. A. Kuchkin. Zhilishchno-Kommunal. Khoz., v. 8, No. 2, 1958, pp. 6-8 (Russian).

Rain water and melted snow, collected from the roofs of dwellings in various districts of Sverdlovsk, Perm, Chelyabinsk, and Nizhni Tagil were analyzed. The pH of the water was found to be higher than values previously reported and increased with time. For example, rain water in the suburbs of Sverdlovsk had a pH of 6.9, snow was 7.2 on the day it fell, and this increased to 7.5 in 10 days. In general, atmospheric precipitation in the Ural regions varied in pH between 6.4 and 8.5, although even higher values were observed in certain industrial regions. Dust fall in certain unspecified locations in the Urals was reported to be 400 tons/sq km/year and was even higher in industrialized regions. A chemical analysis of melted snow taken in metropolitan Sverdlovsk varied as follows (1st value is on day of snowfall and the 2nd is 10 days later): alkyls 1.04 and 1.23 meq., free CO_2 3.3 and 4.1, sulfates 132.5 and 172.7, and total dry solids 288 to 396 mg/liters. Analogous results are reported for precipitations in other locations. The high pH values are attributed to the presence of fuel-ash particles. Waters derived from atmospheric precipitation are corrosive to steel. The following amounts (mg/24 hours) of steel were etched by the waters listed (rain water first,

then melted snow) for the following areas in Sverdlovsk: 0.320 and 1.09 in the suburbs; 0.504 and 1.86 in the center of the city; 0.949 and 2.20 in the industrial districts. Samples of sheet steel of varying composition (obtained from 3 different plants) were subjected to corrosive attack by filtered and unfiltered melted snow. The latter was approximately as corrosive as a 3 percent NaCl solution. Suggestions are made for selecting more resistant steels and for roof design to minimize the holding of snow.

4. Durability Tests of Structural Sandwich. E. W. Kuenzi and L. W. Wood. Symposium on Some Approaches to Durability in Structures, ASTM STP 236, American Society for Testing and Materials, 1958, pp. 27-34.

This paper presents the results of tests and a discussion of the behavior of structural sandwiches having facings of plywood, hardboard, cement-asbestos board, aluminum, and porcelain enameled, steel-faced hardboard on cores of resin-treated paper honeycomb. The construction and behavior of these sandwiches in a structural unit erected 10 years ago are discussed. Also presented are results of "accelerated aging" exposures that are of aid in predicting the durability of such constructions.

5. Effect of Production Features on Building Construction of Titanium-Magnesium Plants. V. N. Romanov. Legkie Metally (Leningrad) Sbornik, No. 1, 1958, pp. 34-40 (Russian).

Operating experience of U.S.S.R. magnesium plants showed that Cl, HCl, and dust containing KCl and $MgCl_2$, discharged into the atmosphere, deteriorate concrete, wood, slag blocks, regular steel, and other building materials. Burned red brick is relatively more resistant. Stray currents destroy the reinforcement metal of underground reinforced concrete structures. Application of multilayer protective coatings of perchlorovinyl paints and lacquers does not provide lasting protection of structures in the presence of HCl and high moisture. Such coatings are preserved sufficiently well at normal moisture, protecting structures from destruction. Recommendations are developed for the construction of titanium-magnesium plants, providing for the use of red brick mark 100 with cement mortar M-50 with cement plaster for inside surfaces, in departments where corrosive gases and liquids are liberated. Foundations in electrolytic departments should be of unreinforced concrete, and should be coated with bitumen, first as a gasoline solution to fill the pores, and then with hot bitumen. Departments are classified according to the corrodibility of the media. A complete set of recommended protective measures is given.

6. Field and Laboratory Investigations on Resistance of Steel Products to Atmospheric Corrosion. L. Jassowicz. Prace Inst. Hutnic., v. 10, 1958, pp. 226-236.

The laboratory methods were based on a salt chamber containing a 3 percent solution of NaCl, or on a humid atmosphere containing SO_2 . The resistances against atmospheric corrosion of "Corten" steel, and 2 low-C

steels were compared. Corten steel contained C 0.12, Mn 0.47, Si 0.58, P 0.180, S 0.021, Cr 0.88, Ni 0.12, and Cu 0.27 percent, the two other low-carbon steels contained C 0.10 and 0.04, Mn 0.35 and 0.13, Si 0.06, P 0.020 and 0.010, S 0.037 and 0.044, Ni 0.15, and Cu 0.09 and 1.15 percent. Ten observation stations were located in industrial, urban-industrial, sea shore, and mine environments. Weight losses were determined at four 10-month periods for over 3 years. The corrosion test results were correlated with humidity and rainfall, and coefficients of the relation between corrosion and atmospheric factors were determined. A considerable divergency between the results obtained by accelerated laboratory tests, and in the field was observed. Whereas the accelerated laboratory tests showed similar resistance against corrosion for all 3 steels, long-time field tests revealed considerably better properties of Corten steel, as compared with low-carbon steels. The carbon steels behaved alike in the open country and industrial atmospheres, but in the sea-shore atmosphere the steel containing 0.10 percent carbon showed higher resistance to corrosion.

7. Influence of Dust and the Atmospheric Corrosion of Metals. K. Barton. Werkst. Korros., v. 9, Aug. Sept. 1958, pp. 547-549 (German).

Corrosion tests on unprotected steels, Cu, Zn and Al in presence and absence of sulphur dioxide at different humidities were carried out in the presence of dust. The effects of properties of several natural and artificial dusts which may influence corrosion processes. Absorption capacity for water vapor and sulphur dioxide, and the composition of dusts and their pH-value are discussed.

8. Role of Condensation in Corrosion of Steel by Moisture and Sulfur Dioxide. B. Sanyal and D. V. Bhadwar. Ind. Research (India), v. 17B, 1958, pp. 287-288.

Heating steel panels in contact with H_2O or enclosing them in a heated cage substantially eliminated corrosion owing to condensation of moisture on the metal surface. In the absence of condensation, H_2O is not available on the metal surface for dissolving SO_2 , which causes corrosion on further oxidation.

9. The Corrosion of Metals and Metal Castings in Industrial Atmospheres. G. Schikorr. Schweiz. Arch. angew. Wiss. Techn., v. 24, No. 2, 1958, pp. 33-46.

The composition of the atmosphere in different industrial areas is discussed. The main source of corrosive attack, apart from the oxygen and moisture contents, is SO_2 and SO_3 from industrial fuels. Corrosion is accelerated by the formation of unstable sulphates which hydrolyse to H_2SO_4 .

1957

1. Corrosion Research. The British Iron and Steel Research Association.
Part I--Corrosion of Bare Ferrous Metals. J. C. Hudson. Corrosion Technology, Sept. 1957, pp. 320-324.

The Corrosion Committee, which was constituted in 1928 and is now under the aegis of the British Iron and Steel Research Association, has been investigating corrosion problems for nearly 30 years. This article summarizes the most important results obtained. They relate to atmospheric corrosion where the resistance to attack can be appreciably augmented by the use of low-alloy steels, to corrosion by fresh and salt waters, and to corrosion by soil. Extensive researches have also been made on the protection of ferrous metals by paints and metal coatings.

2. Corrosion Research. The British Iron and Steel Research Association.
Part II--Protective Measures. J. C. Hudson. Corrosion Technology, October 1957, pp. 349-362.

In the second part of his paper, J. C. Hudson summarizes the studies done on atmospheric corrosion protection of ferrous alloys, especially the use of paints and metallic coatings. He enumerates the conditions required for an efficient protection by paint.

3. Determination of the Corrosion Power of the Atmosphere.
N. D. Tomashov and G. K. Berukshtis. Trudy Inst. Fiz. Khim., Akad. Nauk S.S.S.R., No. 6, Novye Metody Fiz. Khim. Issledovaniy, No. 2, 1957, pp. 50-55 (Russian).

The application consists of 30 alternate plates of copper and iron separated by thin paper saturated with Bakelite. The copper plates were connected in parallel with the iron plates. The corrosion power of the atmosphere was determined by the current generated. More consistent results were obtained with plates coated with the product of oxidation.

4. The Corrosion of Metals Caused by Hygroscopic Solids. A. Bukowiecki.
Schweiz. Arch. angew. Wiss. u Tech., v. 23, 1957, pp. 97-104.

The vapor pressure of the saturated solution of the salt (I) is more important than the atmospheric H_2O vapor pressure (II) in the corrosion of metals. About 0.2 grams of finely powdered dry $Na_2SO_4 \cdot 10H_2O$, KCl , $NaCl$, $NaNO_3$, $NaNO_2$, $NaBr \cdot 2H_2O$, $NaI \cdot 2H_2O$, or $LiCl \cdot H_2O$ was placed on clean steel plates in a desiccator at fixed II at 20° . Noticeable corrosion occurred when II exceeded I, with the exceptions of KCl and $NaCl$: if corrosion occurs when II is below I an impurity more hygroscopic than the salt tested is present. Similar experiments with washed and unwashed samples of natural and blue-colored silica gel, and with washed and HCl -containing rust, show that insoluble porous substances containing large amounts of sorbed H_2O have no corrosive action unless a soluble impurity is present.

5. The Effects of Air Pollution on Buildings and Metalwork. R. J. Schaffer. Air Pollution, edited by M. W. Thring, Butterworth Scientific, London, 1957, pp. 58-71.

This paper discusses the effects of sulfur dioxide, chloride, ammonium and particulate matter on the corrosion and deterioration of materials. It also presents some historical information of interest in air pollution.

6. The Mechanism of Atmospheric Iron Corrosion in the Presence of Sulfur Dioxide as the Aggressor. Z. A. Iofa and G. G. Besproskurnov. Zhur. Fiz. Khim., v. 31, 1957, pp. 2236-2243.

The corrosion rate of Armco iron was measured on a quartz spring balance by suspending a piece of foil 0.05 mm thick over H_2SO_4 solution or 2N H_2SO_4 + varying amounts of Na_2SO_3 (O_2 in the apparatus was previously displaced with H_2 or N_2). The initial corrosion rate was increased at higher SO_2 concentration in the atmosphere; a lower humidity reduced the corrosion rate, and at a relative humidity of 65-70 percent the corrosion was practically absent. After 25-30 hours of corrosion in moist air, the rust formed retarded further corrosion and the rust layer was thicker at higher SO_2 concentration in the atmosphere. Corrosion started in moist air containing SO_2 , continued in SO_2 -free moist air, but at a lower rate. An analysis of the rust made, by using S^{35} in the O_2 -free atmosphere showed that the Fe:S ratio was 1:0.33, and the ratio did not change with the corrosion time. In the presence of O_2 the ratio became lower with time. The corrosion proceeded by an electrochemical process on the iron surface under a film of H_2O . Sulfur dioxide, dissolved in the film, behaved as an oxidizer, depolarized the cathode reduction, and was reduced to sulfur, which stimulated the anodic reaction. In the air, O_2 depolarized the cathode process and oxidized Fe^{2+} to Fe^{3+} ; the SO_3 --apparently catalyzed the oxidation reaction.

1956

1. A Study of Nonprotective Rust Formation on Auto-Body Sheet Steel. J. C. Holzworth, R. F. Thomson and A. L. Boegehold. SAE Transactions, v. 64, 1956, pp. 221-227.

Although average car life has jumped in 30 years from 6-1/2 to 13-1/2 years, improvements in service life of body structures have not kept pace with increased durability of engines and other mechanical parts. Hence the growing interest in improving corrosion resistance of the sheet steels used in auto bodies. This paper reports results obtained in cyclic humidity accelerated corrosion tests aimed at finding a cheap, easily formed sheet steel with better resistance against the sheltered corrosion which causes the most serious body damage. The test produces in 20 days the same kind of nonprotective rust formed in years of outdoor exposure.

Since high-carbon steels, shown in the tests to be the potent corrosion reducers, cannot be used in auto bodies because of their poor

forming characteristics, efforts are now being directed toward finding a combination of elements that will produce the same results without a cost or forming penalty.

2. Atmospheric Corrosion Behavior of Some Nickel Alloys. H. R. Copson. Atmospheric Corrosion of Nonferrous Metals, ASTM STP 175, American Society for Testing and Materials, 1956, pp. 141-158.

The results of the ASTM 20-year atmospheric exposure tests on nickel alloys are discussed. Nickel and high-nickel alloys are very resistant to corrosion at marine and rural locations. In severe industrial locations, the corrosion is more pronounced. For Ni, Ni-Cu alloys and Ni-Fe alloys high in nickel, the attack is essentially uniform in nature, and the corrosion rate is constant with time. In alloys containing appreciable amounts of chromium, the attack is local and of a pitting type. Sheltered specimens corrode more than boldly exposed specimens, and screen and wire corrode faster than does sheet. Nickel-copper alloys in marine locations showed less corrosion of nickel than of copper; additions of nickel to copper are beneficial. At industrial locations nickel corroded more than did copper; substantial additions of nickel to copper increased the corrosion. Monel corroded less than did nickel when boldly exposed. In the nickel-iron series, additions of up to 20 percent of iron to nickel decreased the corrosion somewhat at an industrial location; with larger amounts of iron the corrosion increased. However, with sufficient iron, adherent rust coatings formed which were protective and caused the corrosion rates to decrease with time to fairly low values. Nickel steels form protective rust coatings and corrode much less than do plain steels. Chromium additions to nickel decreased the corrosion markedly, but the attack tended to localize and become pitting corrosion type, especially in sheltered exposure. The addition of iron to nickel-chromium alloys decreased the pitting and made the rust more uniform. With stainless steels, chromium content was the most important factor in determining corrosion behavior on bold exposure; under these conditions the usual grades of stainless steel were essentially unattacked. In a sheltered condition only those stainless steels containing molybdenum remained unattacked. This was especially true of screens.

3. Atmospheric Corrosion by Nuclei. R. St. J. Preston and B. Sanyal. J. Appl. Chem. (London), v. 6, Pt. 1, 1956, pp. 26-44.

Bare and varnished steel contaminated by nuclei produce, in humid atmospheres, the type of corrosion characterized by filamental configuration and known as filiform. With some nuclei, corrosion takes place at relative humidities below 60 percent. Filiform corrosion is characteristic of, and the primary phase in, electrolytic corrosion in atmospheric conditions, but the rate of attack varies from one electrolyte to another and with the degree of humidity. In several cases, corrosion attack has been found to be greater at 70 percent relative humidity than at 99 percent relative humidity. The presence of highly hygroscopic salts in the atmosphere can initiate corrosion, even at low relative humidities. Nuclei on the outside of a varnish film will generally start corrosion

earlier than those beneath the film, especially if water is present on the surface.

4. Atmospheric Corrosion of Metals. B. Sanyal and G. K. Singhania. J. Sci. Ind. Research (India), v. 15B, 1956, pp. 448-455.

Mild steel and zinc were exposed on outdoor unsheltered racks in a semi-industrial atmosphere. Corrosion rates obtained were: 1869 mg/sq dm/yr for steel and 27 for zinc.

5. Corrosion of Cast Iron. R. I. Higgins. Brit. Cast Iron Research Association--J. Research and Development, v. 6, No. 4, Feb. 1956, pp. 165-177.

The behavior and suitability of cast iron in various conditions and media of corrosion is described. Unalloyed and low alloy cast irons and high alloy cast irons including austenitic, high silicon and high chromium cast irons are discussed. Their behavior under varying conditions of acid and alkali environment. The corrosive action of salt solutions, natural and industrial waters, atmospheric and soil corrosion is examined.

6. Corrosion Studies. X. The Mechanism of the Atmospheric Corrosion of Metals in Moist Atmospheres Contaminated With Sulfur Dioxide. K. Barton and E. Beranek. Chem. Listy, v. 50, 1956, pp. 1388-1398.*

The course of the atmospheric corrosion of Fe, Cu, Zn, and Al in the atmosphere contaminated with SO₂ is controlled by the hydrolytic reactions in which solid corrosion products are formed and by the physical-chemical properties of these products. A reaction mechanism is suggested.

7. Galvanic-couple Corrosion Studies by Means of the Threaded Bolt and Wire Test. K. G. Compton and A. Mendizza. Atmospheric Corrosion of Nonferrous Metals, ASTM STP 175, American Society for Testing and Materials, 1956, pp. 116-125.*

Bolt and wire galvanic couples comprising a variety of dissimilar metals were exposed by the Bell Telephone Labs. and by the A.S.T.M. The assembly used a threaded rod 1/2-in. in diam., cleaned in petroleum ether; the precut wires of various composition were cleaned with abrasive and petroleum ether and weighed. Wires were wound on bolts and secured; excess wire was cut off and weighed, and subtracted from the original weight. Specimens were arranged horizontally so that drip from one specimen did not contaminate another. Many of the tests used Mg wires; other tests used Zn, brass, Al, Sn, Pb, and Fe wire. A.S.T.M. specimens were cleaned in accordance with A.S.T.M. Method B 185, and Bell Telephone Lab. specimens were cleaned electrolytically after exposure. A table is given of the average weight loss per 100 days for Mg wires with various bolt materials; there was least loss with Al and greatest with Fe and Ni. The reproducibility of the tests appears to be consistent with that of

other types of atmospheric exposure. Differences in the corrosivity of the atmospheres at different times and at different seasons must be considered when tests are of short duration. No very broad generalizations as to the relative severities of corrosion of dissimilar-metal galvanic couples can be made; each couple must be considered individually in a particular environment.

1955

1. Atmospheric Galvanic Couple Corrosion. K. G. Compton, A. Mendizza and W. W. Bradley. Corrosion, v. 11, No. 9, 1955, pp. 35-44.

Tests designed to provide fundamental information explaining the behavior of galvanic couples in the atmosphere are reported. The purpose is to permit prediction of their probable relative behavior. Measurements of weight losses of couples in a marine, an industrial and a severe tropical atmosphere are reported. Tests involving thin sheet electrode material separated by filter paper saturated with electrolyte are reported. Materials tested include aluminum, magnesium, stainless steel, copper, cadmium, zinc, nickel, tin, chromium, lead electroplate, silver, low carbon steel and others. Potential measurements and weight loss data are given. Specimens exposed to the atmospheres show several apparent weight loss anomalies. Measurements of corrosion currents described provide a quick means for determining probable relative corrosion behavior of couples. Differences between couples "exposed" and "sheltered" are noted. Quantitative data provided are intended to be useful to the design engineer.

2. Corrosion Aspects of Air Pollution. L. Greenburg and M. B. Jacobs. Amer. Paint J., v. 39, No. 43, 1955, pp. 64-78.

This article deals with the corrosive agents carried in the atmosphere such as: (1) Oxygen and oxidants, (2) Acidic materials, (3) Salts, and (4) Alkalis. It discusses how the following materials are attacked: (1) Metals and alloys, (2) Building materials such as stone and masonry, (3) Textile materials, (4) Leather, (5) Rubber, and (6) Protective coatings. The effect of weather and bacterial deterioration are also discussed.

3. Destructive Effects of Air Pollution on Materials. A. Parker. Colliery Guardian, v. 191, No. 4937, October 13, 1955, pp. 447-450.

Main uses of fuels, estimates of pollutants discharged in Great Britain in 1954, distribution of pollution, pollutants as source of sulphurous and sulphuric acids, destructive effects on stone, masonry, iron, steel, leather, and paper are discussed.

4. Metal Coatings on Steel in Contact With Aluminum Alloys. Some Comparative Corrosion Tests. S. C. Britton and R. W. de Vere Stacpoole. *Metallurgia*, v. 52, 1955, pp. 64-70.

Steel nuts and screws coated with Zn, Cd, or Sn-Zn alloy were exposed, in contact with 5 aluminum alloys, to suburban and industrial marine atmospheres, to intermittent immersion in the sea, and to salt spray in the laboratory. The 5 aluminum alloys were commercial purity aluminum, 5 percent Mg alloy, Mg-Si-Mn alloy, 4 percent Cu-Mg-Si-Mn alloy, and HSI5 clad with pure aluminum. None of the 3 coatings gave protection for more than a few years. Coatings of zinc and cadmium protect both steel and adjoining aluminum until they are consumed. Thereafter, corrosion of the aluminum is accelerated, considerably in marine environments but only slightly inland, and some rusting of the iron occurs. Tin-zinc is the most useful general purpose coating of the three. Electrode potentials of single metals in chloride solutions were not very helpful in predicting the performance of bimetallic couples, but measurement of the current flow between the two metals gave useful results.

5. The Corrosion Resistance of Low-Alloy Steels. J. C. Hudson and J. F. Stanners. *J. Iron Steel Inst.*, v. 180, July 1955, pp. 271-284.

Sixty steel compositions including those with small percentages of Ni, Cu, Cr, Al, Mo, V, W, Sb, As, Sn, Cd, Pb, Bi, Ta, Nb, and Be were studied under atmospheric and sea water exposure. The most useful alloying elements for increasing corrosion resistance are Cr, Cu, and Ni. Aluminum and beryllium may also be of value. None of the other alloying elements tested had a marked effect on the resistance of steel to atmospheric corrosion. The most resistant low-alloy steels rust during the first year or two of exposure at only one-third the rate of unalloyed mild steel. With longer exposure, they have still greater advantage. When immersed in sea water, low-alloy steels show to less advantage but under stagnant conditions the addition of 3 percent chromium to mild steel decreased the corrosion loss over 5 years to about half. High-carbon steels are less corrodible in the atmosphere, but more so in the sea with a difference of about 20 percent compared to low-carbon steel. Heat-treatment is not a major factor in corrosion over long periods of exposure, but may have an influence in laboratory tests extending over a few weeks only. There is little difference in the general corrosion of cast Fe and steel when immersed in sea water. Laboratory tests of the intermittent spray-type yield only fair correlation with the results of outdoor exposure. Particularly for atmospheric exposure, marked improvement in the corrosion resistance of structural steels results from small additions of suitable alloying elements.

6. The Destructive Effects of Air Pollution on Materials. A. Parker. 6th Des Voeux Mem. Lecture, Proc. 22nd Annual Conf., Nat. Smoke Abatement Soc., Bournemouth, England, September 28, 1955, pp. 120-132.

British experience on the effects of dirt, grit, smoke, and aqueous acidic materials on brick and stonework, iron, steel, and other metals, leather, paper, textiles, etc. is reviewed.

1953

1. Atmospheric Corrosion of Metals at Relative Humidities Below 100 Percent. V. V. Skorchelletti and S. E. Tukachinskii. J. Appl. Chem. USSR, v. 26, 1955, pp. 27-35.

Films of moisture up to 20 molecular-layers thick were studied on aluminum, iron, copper, tin, silver, and platinum. Preliminary adsorption of CO₂ or SO₂ does not change the adsorption of H₂O on these surfaces. At 100 percent relative humidity (RH) the adsorbed water film behaved like ordinary water in its properties and the solubility of SO₂ was proportional to its partial pressure, but at lower RH this was not true. The critical RH above which iron corrosion rapidly increases was about 85 to 90 percent. The critical RH was substantially reduced when the metal surface was covered by corrosion products. There is hysteresis in the effect on corrosion of increasing and decreasing humidity evidently due to time lags associated with wetting and drying of the corrosion film. The critical RH for copper steel is higher than for copper-free types and is related to the colloid-chemical properties of the rust.

2. Corrosion of Iron and Steel and Its Prevention. J. C. Hudson. Dock & Harbour Authority, v. 34, No. 392, June 1953, pp. 47-53; No. 393, July 1953, pp. 81-84; No. 394, August 1953, pp. 111-116; No. 395, September 1953, pp. 143-146.

The theory of atmospheric, aqueous, and microbiological corrosion and the corrosion of bare ferrous metals under conditions encountered in docks and harbors is discussed. Available methods for corrosion prevention, including cathodic protection, use of corrosion resistant materials, and protective coatings, is surveyed.

3. Corrosion Resistance of High-Strength Low-Alloy Steels as Influenced by Composition and Environments. C. P. Larrabee. Corrosion, v. 9, No. 8, 1953, pp. 259-271.

The corrosion resistance of several high-strength, low-alloy steels in various types of atmospheres are compared to those of copper-bearing steel and carbon steel. Local atmospheric contamination can have an effect on corrosion rates and accounts for the difference in corrosivity within a comparative similar area. For example, galvanized steel panes that had coating weights either of 1.25 oz/ft² or 150 oz/ft² and were exposed in the rural atmosphere of State College, Pennsylvania showed rust after 14.6 and 17 years, while those exposed in the industrial atmosphere of Altoona, Pennsylvania showed rust after 2.4 and 3.0 years. Perforation of the panels occurred at State College and Altoona after 24 and 4.3 years, respectively. Time (month or season of the year) of exposure and

the weather conditions immediately after exposure affect corrosion rates. The direction of exposure, the degree of shelter, and relative humidity also affect the corrosion rate.

4. Effect of Climate and Atmospheric Pollution on Corrosion. J. C. Hudson and J. F. Stanners. J. Appl. Chem. (London), v. 3, pt. 2 February 1953, pp. 86-96.

Routine observations on corrosion of small reference specimens of ingot iron and of zinc exposed at atmospheric testing stations of the Corrosion Committee all over world are given. Data which relate to more than 20 sites and to up to 20 separate annual tests at each site provide good indication of effect of climatic differences on atmospheric corrosion.

5. Effect of Composition of Steel on the Performance of Organic Coatings in Atmospheric Exposure. F. L. LaQue and J. A. Boylan. Corrosion, v. 9, No. 7, 1953, pp. 237-241.

Steels showed a 20 to 1 difference in corrosion loss between exceptionally low copper-content open-hearth iron and a typical low-alloy high-strength steel. A common automobile paint system was used, a pigmented baking alkyd primer with pigmented baking urea-modified alkyd top coats, with and without zinc phosphate (Bonderite) pretreatment. These panels were exposed 80 and 800 feet from the ocean at Kure Beach, North Carolina, in an industrial atmosphere at Bayonne, New Jersey, and in a rural atmosphere at Morenci, Michigan. Principal findings were that low-alloy steel performed best; copper-steel next. Low-copper-content open-hearth iron was the worst, painted or bare. Zinc phosphate pretreatment improved performance of all painted steels, the advantage increasing with severity of the atmosphere and vulnerability of steels. Best performance was that of low-alloy high-strength steel, zinc phosphate pretreated. A few weeks' exposure 80 feet from the ocean led to the same conclusions as exposure for much longer periods elsewhere. Marine exposure 800 feet from the ocean was less damaging to bare, but more damaging to painted steel than the Bayonne industrial atmosphere.

1952

1. Atmospheric Corrosion of Low-Alloy Steels. H. R. Copson. Am. Soc. Testing Materials, Preprint No. 70, 1952, 22 pp.

In 1941 five sets of 71 low-alloy steels were exposed to the industrial atmosphere at Bayonne, N. J., and to the marine atmosphere at Block Island, R.I. This paper gives the weight losses, pit depths, thickness measurements, calculated pitting factors, and the weight of the rust on the specimens through 9 years. Even after 9 years the lowering of the surface level was only 1 mil or less for all the better steels. Most of the attack occurred in pits, and pit depths were important. Pit depths did not rate the steels in the same order as weight losses. For example,

steels containing chromium tended to have fewer but deeper pits, and steels containing nickel tended to have more but shallower pits. Alloying decreased both pit depths and the number of pits, but the beneficial effect of alloying was more marked in decreasing weight losses than pit depths. The new data confirmed the beneficial effect of fractional percentages of copper, of small amounts of phosphorus, and of a percentage or more of nickel. Nickel additions produced low initial weight losses, and on long exposure nickel was particularly effective in decreasing pit depths. Chromium was particularly effective in flattening weight loss time curves. Chromium and copper additions to complex steels were more helpful at Bayonne, and manganese was more helpful at Block Island. Pit depths continued to deepen with time at Block Island, whereas at Bayonne pits were scarcely any deeper at 9 years than at 5 years. All the time curves continued to diverge, meaning that the benefit of alloying increased with time.

2. Corrosion of Different Metals in Liquefied Sulfur Dioxide. J. Bollinger. Schweiz. Arch. angew. Wiss. u. Tech., v. 18, 1952, pp. 321-342.

A survey is given of the physical and chemical properties of SO_2 (gas and liquid). The metals studied are: Fe, Al, Cu, and some of their alloys; Zn, Ni, Cr, Cd, Pb, and a Mg-Si alloy. The tests show that corrosion by SO_2 is possible only in the presence of water; the presence of oxygen activates the attack but in most cases corrosion can proceed without it. The attack is either uniform or nonuniform according to the type of surface layer generated. Experiments on the efficiency of various organic inhibitors are recorded.

3. Corrosion of Metals. U. R. Evans. Soc. Chem. Industry (Chem & Industry), No. 41, October 11, 1952, pp. 986-993.

Corrosion of nonferrous metals and of iron in early times, early views of electrochemical mechanisms, hydrogen liberation and oxygen reduction, oxidation, tarnishing and atmospheric corrosion, stress corrosion, inhibitive water treatments, cathodic protection, and protective coatings are discussed..

4. Second Report of the Methods-of-Testing (Corrosion) Subcommittee. J. Hudson and others. J. Iron and Steel Inst. (London), v. 171, 1952, pp. 255-272.

The A.R.E. test in accordance with Provisional B.S. 1391 (1947) for a period of 28 days gives a reasonable indication of the service performance of protective coatings. A new sulfur dioxide corrosion test developed at the Chemical Research Laboratory, Teddington, consists in exposing specimens inside a covered beaker containing a dilute solution of SO_2 . Moisture is caused to condense on the specimens by use of an electric heater and a cooling coil. This test gives fair correlation with the results of outdoor exposure tests and is satisfactorily reproducible in different labs. Interim results for 5 years exposure in the original

field test show less correlation with the results of laboratory tests without SO₂ than was found after 1-1/2 years exposure.

5. Some Further Observations on the Painting of Aluminum Alloys.
W. A. Edwards. Light Metals, V. 15, No. 167, 1952, pp. 61-63.

Sixteen specimens of aluminum-alloy sheet, with one each of mild steel, brass, and copper, were exposed to the atmosphere for 50 months at an angle of 45 degrees facing south. They were weighted before exposure and were removed at intervals for reweighing and scrubbed with warm H₂O to remove excess surface dirt. The steel specimens were derusted with Clarke's solution. The steel rapidly lost weight, but owing to the impossibility of cleaning the remaining specimens perfectly, no loss of weight was found. After 50 months, the surface of each was thoroughly cleaned of dirt and corrosion products by immersion in a solution of H₃PO₄ and CrO₂ at 80° for 1 minute, followed by a vigorous brushing under a stream of H₂O. The specimens were then dried and weighed. When the differing original weights are taken into consideration, the losses expressed as a percentage of these, range from 0.30 percent to 0.53 percent for the aluminum alloys, as compared with 60.2 percent for steel, 0.70 percent for copper and 0.96 percent for brass. This indicates that the resistance of the various alloys falls into approximately the same order whether the corrosive environment is salt solution or a mild industrial atmosphere.

1951

1. Adsorption of Water Vapor on Solid Surfaces. W. H. J. Vernon. Nature, v. 167, 1951, pp. 1037-1038.*

The adsorption of water vapor by metal surfaces is negligible provided that both metal surface and the atmosphere are free from contamination. Iron was particularly susceptible to the presence of disperse solid particles, for example, traces of (NH₄)₂SO₄. Nickel provided an extreme case of susceptibility to gaseous pollution, for example, traces of SO₂.

2. Corrosion Testing. F. L. LaQue. Proc. American Society for Testing and Materials, v. 51, 1951, pp. 495-582.

This paper was the 25th Edgar Marburg Lecture and is a comprehensive discussion of the state of corrosion testing. Separate sections are devoted to atmospheric corrosion, corrosion in waters, galvanic corrosion, salt spray tests, immersion tests, plant corrosion tests, and tests of paint.

3. Historic Church's Copper Roof Good After 213 Years. A. W. Tracey. Corrosion, v. 7, No. 11, 1951, pp. 373-375.

An examination of English-made copper sheets taken from the roof of Christ Church, Philadelphia, Pennsylvania after 213 years' exposure shows a weathering loss of 0.007-inch at the thinnest areas, equivalent to a corrosion rate of 0.000033-inch per year. It is believed the essentially rural character of the atmosphere during early exposure of these sheets has contributed to their life. Recent corrosion tests on copper sheets in an industrial atmosphere show somewhat higher rates. Rockwell hardness of 15T 61 to 63 indicated the sheets on the church had been finished with a slight temper. Screws driven through the center of some sheets twenty years ago restricted expansion and contraction and caused fatigue cracks. Some of the 3-inch wrought iron nails originally used to fasten the copper pans to the roof boards had corroded through at the roof line, possibly as a result of condensation.

4. Ohio River Division (U.S. Corps of Engineers) Corrosion Problems. J. A. Davenport. Corrosion, v. 7, 1951, pp. 42-46.

Cooperative studies and tests on stainless steels, low-alloy steels, carbon-steels, and aluminum have been conducted. Of the common low-alloy steels tested, Cor-Ten alone showed any superiority. An apparent anomaly is the improved performance of both Cor-Ten and structural steel when welded together in the Monongahela tests. In the alloy-steel tests, the only outstanding material is a recently patented chromium-titanium grade of steel, not yet available commercially. Tests on aluminum have indicated both corrosion and erosion resistance. Results are given for different types of painting tests, including varnishes and vinyls. On some recent contracts for submerged-type surfaces, the use of phenolic varnish paint for shop coat has been introduced. For atmospheric exposure only, an oil base paint is used as a shop coat, with field coats of Al in phenolic varnish. Earlier tests with vinyl and chlorinated rubber paints failed, owing to incompatibility between the old and new paint. The old paint coatings should be removed before applying a wash primer when vinyls are used as finish coats. For heavy coating, three coats are applied, with the second sanded.

5. Rust Formation on the Surface of Steels Under the Atmospheric Conditions in Japan and Its Prevention. M. Tagaya and S. Isa. Technol. Repts., Osaka Univ., v. 1, 1951, ppp. 279-285.

Rust particles formed on the polished surface of steel in the atmosphere are classified as dotted, granular, threadlike, and lumpy rust. In these rusts only some of the lumpy rusts grow rapidly and become so-called "iron rust." The lumpy rusts are produced by a number of dew drops condensed on the steel surface. Lumpy rust generally starts in the pearlite area and not in the ferrite area of steels. Therefore, high-carbon steels rust more rapidly than low-carbon steels. Similarly, the decarburized high-carbon steels are more resistant to rust. Steel containing copper above 0.2 percent is resistive to rust than the one containing copper below 0.1 percent. Six-tenths percent carbon steel is quenched from 800° and tempered at lower temperature. Dust adhering to the steel surface, soluble chlorides, and sulfates have a strong accelerating action. Fe₂O₃ particles also have some accelerating

action. On the other hand, SiO_2 , Al_2O_3 , and CaO particles show nearly no action. If the steel surface initially bears a complete oxide film (invisible) it is more resistant to rust. Therefore, steels finished by proper electrolytic treatment, held in dry air for a long period, or immersed in 0.5 percent $\text{K}_2\text{Cr}_2\text{O}_7$, 0.1 percent Na_2HPO_4 solution showed good resistivity. The initial flowing current from the surface of steel wire bearing a complete oxide film immersed in 1 percent H_2SO_4 increases slowly and requires a long time to reach constant current density. The resistance to rust formation is indicated by measuring the flowing current. Among the rust-preventive oils, petrolatum and animal oils have greater protective action than vegetable and mineral oils.

6. The Effect of Copper Undercoats on the Protective Value of Nickel-Chromium Coatings on Steel. B. B. Knapp and W. A. Wesley. *Plating*, v. 38, 1951, pp. 36-38, 45-48, and 53-55.

Atmosphere, salt spray, and hot water tests of plated high-carbon steel panels showed a copper undercoat to be detrimental to corrosion resistance of the nickel-chromium coatings. Copper and iron corrosion products were found to accelerate corrosion of nickel-chromium coating.

1950

1. Application of an Accelerated Atmospheric Corrosion Test to the Assessment of Temporary Corrosion Preventives. R. St. J. Preston and E. G. Stroud. *J. Inst. Petroleum*, v. 36, 1950, pp. 457-463.*

An accelerated corrosion test, in which specimens are exposed in a thermostatically controlled humid atmosphere containing sulfur dioxide, has been applied in the assessment of temporary corrosion preventives, including materials ranging from light lubricating oil, through petroleum jelly, to bitumen. The average order of failure of steel panels coated with the protectives, exposed in various parts of the United Kingdom in unheated sheds, approximated to that obtained in the laboratory test of 1 week duration. A plain humid atmosphere was insufficiently aggressive to break down most of the samples, in spite of a prolonged period of test.

2. Atmospheric Factors Affecting the Corrosion of Steel. P. J. Sereda. *Ind. Eng. Chem.*, v. 52, No. 2, 1950, p. 157.

Measurement of temperature, sulfur dioxide, and surface moisture has resulted in systematic evaluation of the atmospheric corrosion of steel and should provide a basis for the rating of inland exposure sites.

1948

1. A Simple Form of Accelerated Atmospheric Corrosion Test.
R. St. J. Preston. J. Iron Steel Inst. (London), v. 160, 1948,
pp. 286-294.

A condensation-type corrosion test in which specimens are subjected to corrosion in a warm humid atmosphere containing sulfur dioxide is used to study plain and phosphated steel with and without paint cover. The extent of corrosion is estimated either by visual inspection with or without a high-reflection meter, or by gain of weight. Loss of weight on removal of corrosion products is a more reliable criterion, especially with heavy attack. An efficient phosphate coating as thick as a thin paint film has corrosion resistance considerably greater than unprotected steel.

2. Atmospheric Durability of Steels Containing Nickel and Copper--Additional Exposure Data. N. B. Pilling and W. A. Wesley. Proc. American Society for Testing and Materials, v. 48, 1948, pp. 610-617.

The prior publication on this subject appeared in 1940 and described six series of weathering tests designed to evaluate the durability of sheet specimens of low-alloy steels containing nickel and copper. The present communication brings up to date the published results of those exposure tests which were continued beyond 1940. In the oldest series, observations at the end of 22 year exposure are now made available. In the series in which large sheet specimens simulate some of the conditions encountered in roofing service, the advantage of nickel-copper steels over copper steels is becoming more impressive as the years pass by. Long-continued tests show that it is more significant to compare steels on the basis of how long a time is required to arrive at a given unit weight loss than to compare them on the basis of weight loss suffered in a fixed period of time.

The beneficial effects of nickel upon the weathering resistance of steel increases with increasing nickel content. Addition of copper to a nickel steel improves the life, but the optimum amount is less than the amount of nickel and remains well below 2 percent even with a 4 percent nickel content. With long exposure periods, there is evidence that not only phosphorus but also silicon additions to nickel-copper steels have a beneficial effect on the behavior in the industrial atmosphere. Effects of manganese and carbon are unimportant in this type of atmosphere.

3. Climatic Effects on the Corrosion of Steel. J. Dearden. J. of the Iron and Steel Inst., v. 159, 1948, p. 241.

An attempt was made to correlate the corrosion of steel in a moderately industrial atmosphere with the hours of rainfall registered by a recording rain gauge. No such relation was found, as only 35-40 percent of the total corrosion occurred during the hours when the rainfall was sufficient to register on the gauge. A further 35 to 40 percent was due to the effects of humidity, and the balance is presumed to have occurred during periods of drizzle and when the specimens remained wet after

recordable rainfall had ceased. Measurements were made of the corrosion rate of previously rusted specimens under various humidities, and a marked increase in the rate was observed when the relative humidity was over 80 percent. A quantitative estimate of the corrosion due to rainfall and to various ranges of humidity has been attempted. Observations were made on the effects of the weather prevailing at the start of exposure, the annual shedding of rust, the expansion when this cannot occur, and the sulphur content of rust formed under various conditions.

4. Factors of Importance in the Atmospheric Corrosion Testing of Low-Alloy Steels. H. R. Copson. Proc. American Society for Testing and Materials, v. 48, 1948, pp. 591-607.

Some applications in the atmospheric corrosion testing of low-alloy steels are brought out. Data are presented which show that it is unsafe to draw general conclusions from tests of limited character. The results obtained depend on the location (whether industrial, marine, or rural), on the duration of the tests (the benefit of alloying increases with time), on the manner of exposure (particularly whether sheltered or boldly exposed), on the method of estimating corrosion (whether weight loss, pit depth, or time to disintegration), and on the weather (particularly as regards wetness and pollution). Under all conditions alloying seems of value, but the magnitude of the benefit and the relative merit of different steels and alloying elements varies. For example, a few weight loss versus time curves have been found to cross. In a thin steel, pit depths become more important than weight losses. Likewise for short exposures the benefit to be obtained by complex alloying may not be worth the additional cost. These effects are illustrated chiefly by means of data obtained through five years of exposure of 71 low-alloy steels at a marine location at Block Island, Rhode Island, and an industrial location at Bayonne, New Jersey.

5. The Atmospheric Corrosion of Ferrous Metals and Its Prevention. J. C. Hudson. Gas World, v. 129, No. 3333, Coking Sect., 1948, pp. 83-102.

The atmospheric corrosion of ferrous metals is shown to be closely connected with the relative humidity and pollution of the atmosphere. Facts regarding its magnitude established by the work of the corrosion committee are reviewed, and the great practical advantages to be derived from the increased resistance of low-alloy steels to atmospheric attack are emphasized. Methods for protection against atmospheric corrosion are considered, with particular reference to the use of paint and metallic coatings.

6. The Atmospheric Corrosion of Iron and Steel Wires. J. C. Hudson. J. Iron Steel Inst. (London), v. 160, 1948, pp. 276-285.

Nine-inch lengths of wire of eight general materials were exposed at Sheffield University for periods up to 10 years. The decrease in breaking load is used to establish the effect of corrosion on the loss in diameter.

The rate of corrosion did not vary with duration of exposure, but was greater for thin than for thick wires. The substitution of low-alloy (for example, 0.6 to 0.9 percent chromium and 0.5 percent copper) steel wire for mild steel wire is indicated where resistance to atmospheric corrosion is required.

7. The Atmospheric Corrosion of Metals. G. Schikorr. Arch. Metallkunde, v. 2, 1948, pp. 223-230 (German).*

Corrosion rate is affected by all atmospheric variables, yet relations are simpler than might be expected and the amount of corrosion per year varies but little. Data shown indicate but little effect on yearly corrosion rate of precipitation or temperature, but it is increased by high humidity and high sulfur content of air. Thus, in winter, high sulfur content from heating houses increases corrosion. Corrosion is slowest in the country, faster in city, still faster in an industrial section, but fastest in sea air. If the sulfur in air comes from locomotives, ship, etc., seasonal changes are not important. Yearly average rate of corrosion was found not higher than either the summer or winter rate, hence the coat formed seems to have a protective action. Resistance to corrosion is related to position in the electromotive series of metals and also to formation of protective films. In ordinary atmospheres, lead and zinc form carbonate films. Against sulfur corrosion, protective films are formed by Fe, Cu, Pb, Cd, Mg, Ni, and Zn, but in an ocean climate, where chloride is the cause of most corrosion, magnesium and iron are more rapidly corroded. Impurities may hasten or retard corrosion. Tests on a number of metals in the atmosphere showed the first month Pb, Zn, brass, Cu, Ni, and marble were corroded at about the same rate owing to sulfur of the air. Presumably this rate would later slow down for metals such as lead and copper which form protective films. Tests of iron and zinc, in which water and also dilute H_2SO_4 were deposited on the metals, showed the iron more corroded by the acid than was zinc, probably due to a catalytic action of the acid, forming $FeSO_4$ which is oxidized by air to the unstable ferric compound. A decrease in these reactions, owing to low temperature might account for a comparatively slow rate of corrosion of iron in cold weather.

1946

1. Corrosion of Steels. J. Johnston. Corrosion and Mat. Proc., v. 3, No. 3, 1946, pp. 9-12.

This is an up-to-date discussion of the corrosion of steels, especially atmospheric corrosion, with a discussion of the value of certain alloying elements and the use of protective nonmetallic coatings.

1945

1. A Theory of the Mechanism of Rusting of Low Alloy Steels in the Atmosphere. H. R. Copson. Am. Soc. Test. Mat. Proceedings, v. 45, 1945, pp. 554-590.

In 1941 exposure tests were started on low-alloy steels in industrial and marine atmospheres. Analyses of selected rust samples are presented, along with an examination of weather data and some weight losses. These results led to a new theory of the mechanism of rusting.

It is postulated that corrosion rate depends on the quality and quantity of water reaching the steel surface. Relatively insoluble corrosion products decrease the amount of soluble constituents in the water and thereby decrease corrosion. Relatively insoluble corrosion products do not wash away, and thereby they decrease the porosity of the rust coating and the quantity of water reaching the steel. As time goes on pores become plugged and the position of low alloy steels improves.

In industrial atmospheres, copper and nickel in steel render sulfate corrosion products more insoluble by forming complex basic sulfates. On mild steel, sulfates in the rust are relatively soluble and promote corrosion but are washed away by rain. On alloy steels the sulfates are less soluble so that corrosion is slower, but less sulfate is washed away and more accumulates in the rust. The percentage of sulfates in the rust increases as weight loss decreases. At the marine location, severe corrosion of certain edges was due to soluble chlorides being swept to these edges by the wash of rain.

Miscellaneous data and references are examined in the light of this mechanism. A factor which has been neglected in the literature is the composition of the film of electrolyte on the steel surface. It has been tacitly assumed that in a given atmosphere each test specimen of steel is exposed to the same environment. Actually, owing to the influence of corrosion products, each steel specimen is exposed to a separate environment.

2. Atmospheric Corrosion Laboratory Test for Ordinary Steels With Low-Alloy Additions. E. Herzog. Metaux, corrosion, usure, v. 20, April 1945, pp.47-51.

An application is described in which specimens were exposed to a humid atmosphere so that small drops of H_2O condensed on the specimen and rusting occurred rapidly. Tests were made to determine the scatter of results with changes in the location of the specimens, the influence of humidity, of small additions of Cu, Cr, Al, P, and S, and of surface condition, and the difference between the classification obtained with the test and that obtained by exposing specimens in an industrial atmosphere. Results are tabulated.

3. Atmospheric Corrosion of Iron. C. P. Larrabee. Blast Furnace and Steel Plant, v. 33, No. 8, August 1945, p. 993.

Under standardized conditions of atmospheric corrosion tests, many combinations of alloying elements in steel produce rust films which

improve the corrosion resistance appreciably over that of copper steel. To reduce corrosion losses below the minimum found for certain low alloy corrosion resistant steels, it is necessary to add alloying elements in amounts disproportionate to their value, due to the fact that, a loss of weight of 6.5 g/sq decimeter of most alloy steels is used up in the formation of the protective oxide film.

1944

1. The Effect of Specimen Position on Atmospheric Corrosion Testing of Steel.
C. P. Larrabee. Trans. Electrochem. Soc., v. 85, 1944, pp. 297-306.

Many methods of exposing atmospheric corrosion test specimens are described. It is shown that steel specimens, when mounted on racks at an angle of 30° to the horizontal, corrode less on the surface exposed to the sky than on the side toward the ground. In applications such as roofs where the under side of the sheet is not exposed, the expected life might be two or more times that indicated by tests where both sides are exposed.

1943

1. The Corrosion of Metals in Air. Jubilee Memorial Lecture.
W. H. J. Vernon. Chemistry and Industry, August 1943, pp. 314-318.

This is a review of some researches conducted on the atmospheric corrosion of different metal alloys. The outstanding promoting factors in atmospheric corrosion are the sulphurous impurities derived from combustion processes. Relative humidity is a controlling factor. The special cases of surface film formation and development on copper and zinc and of film breakdown on iron were presented.

1940

1. Atmospheric Durability of Steels Containing Nickel and Copper.
N. B. Pilling and W. A. Wesley. Proc. American Society for Testing and Materials, v. 40, 1940, pp. 643-657.

The results of six series of atmospheric corrosion tests are presented which evaluate the durability of sheet specimens of low alloy steels containing nickel and copper. Rural, urban, industrial and marine atmospheres are represented at the test sites. The commercial significance of the data is broadened by the multiplicity of compositions tested. The oldest series of exposures is now in its fifteenth year. Another series consists of large specimens simulating some of the conditions to which roofing sheets are exposed in service. The effects of composition variables are studied in one series and the corrosion-time relationship in another. The results of a practical railroad coal car test are also made available.

A general conclusion from this work is that the beneficial effects of nickel upon the weathering resistance of steel increase with increasing nickel content and are enhanced by the addition of optimum amounts of copper. The superiority of nickel copper steels over copper steels is particularly pronounced in a marine atmosphere to which the latter do not respond well. The effects of manganese, silicon and carbon contents do not appear to be important but the presence of a moderate amount of phosphorus seems to be beneficial in nickel-copper steels.

1939

1. Effect of Sulfur Compounds in the Air on Various Materials. L. R. Burdick and J. F. Barkley. U. S. Bureau of Mines, I. C. 7064, April 1939, 9 pp.

This paper presents a review of published investigations dealing with the importance of sulfur compounds in the deterioration of materials or providing some basis for estimating the extent of loss chargeable to such air pollution. Materials included are cement, stone, metals, paint, leather, paper, and cloth. The investigations may be divided into two classes, one of the laboratory type in which the sulfur content and the humidity of the air were controlled and the other dealing with the exposure of materials to atmospheres not under control. The first type of work has shown that cement is subject to deterioration by the action of sulfur dioxide gas. The experiments with stone indicate that although limestone takes up sulfur dioxide from the air, moist sulfur dioxide-air mixtures alone cannot be used for establishing the comparative weathering qualities of the different types of stone by accelerated test methods. Laboratory tests indicate that sulfur compounds in the air accelerate the corrosion of iron, steel, zinc, copper, and nickel at normal air temperatures and at certain relative humidities. It has also been indicated that certain types of paint are affected by high sulfur dioxide concentrations, and that paper is attacked by sulfur dioxide in the atmosphere.

The investigation of the second type show the amount or variation of corrosion in different localities and under different types of exposure. The investigations during which sulfur determinations were made indicate that sulfur dioxide is a main controlling factor in the corrosion of iron and steel but may not be for some non-ferrous metals. In general, the laboratory tests do not give definite data on the loss due to sulfur compounds at the concentrations normally found in the air. The data from atmospheric exposures are not complete from the standpoint of the exact effect of the sulfur compounds. Damage to materials so exposed is affected by factors such as other chemical contaminants, humidity, rainfall, solid deposits, and sunlight. A simple scheme has been devised in Great Britain which is considered to provide a measure of the attack of sulfur compounds on building materials. Small cylinders coated with lead peroxide paste are exposed to the atmosphere for about 1 month, after which the paste is analyzed and the results reported as milligrams of sulfur trioxide per 100 sq. cm. of cylinder per day.

1938

1. Influence of Electrolytes on the Atmospheric Corrosion of Zinc, Aluminum, and Iron. W. S. Patterson and J. H. Wilkinson. J. Soc. Chem. Ind., v. 57, 1938, pp. 445-446.

Finely powdered NaCl and NH_4Cl were suspended in CCl_4 and applied to sheet specimens of wrought Fe, Zn, and Al. The corrosion of these specimens in an atmosphere containing 80 percent humidity was determined at 20° C over periods of up to 100 days by the loss of weight method. With zinc, NaCl accelerated corrosion much more than NH_4Cl , possibly because of the greater hygroscopicity of the NaCl or because of the role of the NH_4Cl in forming the zinc-ammonia complex which tends to produce a cathodic reaction. With aluminum and iron, the NH_4Cl caused greater corrosion than the NaCl, possibly because of the low pH of the saturated NH_4Cl solution. On aluminum, Na_2CO_3 had a corrosive effect similar to that of NH_4Cl . The shape of the corrosion curves indicated the influence of an initially existing oxide layer on the aluminum and the retarding influence of the corrosion products formed on both the aluminum and the iron.

1937

1. Atmospheric Rusting of Iron--II. G. Schikorr. Z. Elektrochem., v. 43, 1937, pp. 697-704.

Parallelism was found between the rate of rusting in the atmosphere and the sulfur content of the air as determined by the absorption bell according to Liesegang. Exceptions were observed in months with long freezing spells. Steel specimens protected against rain rusted at a rate of 50 to 75 percent of that of specimens exposed to rain. In exposures up to 2 years, the rust formed on electrolytic iron and on a steel containing C 0.05, Cu 0.21, Ni 0.05 and Cr 0.03 percent showed definite protective value. On cast iron, this protective effect was much less. It also diminished in a pure country atmosphere and was quite low on specimens protected against rain. Specimens which had been subjected to preliminary rusting to different atmospheres were subjected afterward to exposure in closed vessels containing air with 93 percent humidity. The sulfur content of the preliminary atmosphere had a highly accelerating effect on the subsequent rusting. Dew formed on rusting iron contained much more SO_2 than that formed on glass plates. Humidity and sulfur compounds in the air are assumed as the main causes of atmospheric rusting.

2. The Atmospheric Corrosion of Metals. W. H. J. Vernon. Proceedings Chemical Engineering Group (Soc. Chem. Ind.), v. 19, 1937, pp. 14-22,

Work on the corrosion of copper, nickel, and iron in laboratory and natural atmospheres is reviewed. The tarnish film on copper, produced by hydrogen sulphide, consists of Cu_2S and Cu_2O , and, after the formation of the initial film, the growth is parabolic with time and little affected by changes in the hydrogen sulphide content of the

atmosphere. In the presence of moisture and sulphur dioxide, such as occurs on outdoor exposure, copper becomes covered with a green patina. In rural districts this consists mainly of basic sulphate; in urban districts there is a greater proportion of basic carbonate, and near the sea, of chlorides. The "fogging" of nickel, which occurs in polluted atmospheres when the relative humidity exceeds about 70 percent, consists, in the early stages, of sulphuric acid with some nickel sulphate, and later of basic nickel sulphate. Iron will remain bright in atmospheres of high relative humidity if suspended particles are removed by filtration. The rate of corrosion is greatly increased by the presence of sulphur dioxide although carbon dioxide has an inhibiting effect under some conditions.

Attention is directed to the importance of (i) the principle of critical humidity, (ii) presence of suspended particles, and (iii) the primary oxide film.

1936

1. Atmospheric Rusting of Iron. G. Schikorr. Z. Elektrochem., v. 42, 1936, pp. 107-113.

The rusting of iron plates under atmospheric attack was observed by the loss of weight method during a period of 2 years. No simple relation between rusting and rain precipitation could be found, but a relation between the rate of rusting and the average relative humidity was determined. This relation was explained by the effect of the length of the raining period, by "dry" rusting in the presence of dust or preformed rust at a relative humidity of over 70 percent, and by the fact that in the winter months the relative humidity is related to the H_2SO_4 content of the air, both being increased at lower temperatures. Comparison of rust-free and pre-rusted specimens showed that if the effect due to "wet" rusting is small, the major proportion of the total attack may be due to "dry" rusting. Owing to the protective action of preformed rust, which counteracts its rust-promoting action but does not become distinct until a few months after exposure, an initial acceleration of rusting was followed by a decreasing rate later. The influence of the H_2SO_4 in the air was established by comparison exposures in a rural (forest) atmosphere. The rust formed in the latter showed less protective action than that formed in the city atmosphere. The steel used contained 0.14 percent copper, which probably favored the formation of protective layers.

2. Corrosion Resistance of Metals and Alloys. R. J. McKay and R. Worthington. Amer. Chem. Soc. Monograph, No. 71, Reinhold Publishing Corporation, New York, N.Y., 1936, 492 pp.

Part I is about "General and Theoretical" aspects of corrosion. Rate factors, forms of corrosion, corrosives, metal corrosion properties are discussed. Part II is about corrosion behavior of specific metal and alloy groups: Mg, Al, Zn, Fe and steel, Ni, Cu, etc.

1935

1. Laboratory Study of the Atmospheric Corrosion of Metals. II. Iron--Primary Oxide Film. W. H. J. Vernon. Trans. Faraday Soc., v. 31, 1935, pp. 1668-1678.

Marked differences in properties of oxide films on iron are observed according to whether the film is produced below or above a critical temperature 200° . The equation $d \log W/dt = -Q/RT$ expresses the relation between rate of oxidation and temperature, but there is a change of constant at 200° giving 2 intersecting straight lines with the greater slope above the critical temperature when log oxidation rate is plotted against $1/T$. At higher temperature a parabolic relation ($w^2 = kt$) holds between oxidation rate and time. Below 200° the expression deviates ($w^{2.5} = kt$ approximately). Above 200° the colors produced are consistent with interference of light in a continuous transparent sheath, and any given color may be obtained at different temperature by calculation of the time required to give appropriate thickness. Below 200° the relation between color and film thickness does not hold. The ill-defined colors ultimately obtained suggest a granular film. At 25° a point of inflection in the time-oxidation curve below which deviation from the quadratic parabola is in the reverse direction, at 15 days, is believed to imply completion of unit lattice of oxide over the whole surface. A secondary inflection where ($w^2 = kt$) changes to ($w^{2.5} = kt$) marks the breakdown of this primary film. Electron diffraction experiments show a difference in structure of the film above and below 200° . The diffraction patterns for a sample oxidized at 135° indicates a cubic structure of side 8.4A. This may be due to $\gamma\text{-Fe}_2\text{O}_2$ or Fe_3O_4 . At higher temperatures a rhombohedral structure ascribed to $\alpha\text{-Fe}_2\text{O}_3$ is obtained. Evidence indicates that the crystals were oriented on the surface with a 211 plane parallel to the metal surface.

2. Laboratory Study of the Atmospheric Corrosion of Metals. III. Secondary Product of Rust (Influence of Sulfur Dioxide, Carbon Dioxide and Suspended Particles on the Rusting of Iron). W. H. J. Vernon. Trans. Faraday Soc., v. 31, 1935, pp. 1678-1700.

In purified air of high relative humidity (RH) rusting of mild steel is reduced if the high RH is approached from zero. This is ascribed to the strengthening of the primary film in the early stages. At constant RH, just below saturation, time-corrosion curves are convex about the corrosion axis; under supersaturation conditions they are concave for 70 days, then nearly linear. This is ascribed to changes in primary film. In the presence of sulfur dioxide at approximately 50 percent RH (primary critical humidity) there is a marked weight increase followed at a little higher RH with rust formation. At approximately 80 percent RH (secondary critical humidity) there is a great increase in rate of attack. The primary critical humidity depends upon a relation between concentrations of H_2O , O_2 and SO_2 for rusting to begin. Secondary critical humidity depends upon the properties of the initially formed rust. Differences in the behavior of iron and zinc depend upon secondary critical humidity phenomena. The influences of suspended solid particles depends upon whether (1) they are intrinsically active, for example,

$(\text{NH}_4)_2\text{SO}_4$; (2) neutral, but capable of adsorbing active gases, for example, charcoal; (3) neutral with little adsorptive capacity, for example, SiO_2 . Under supersaturated conditions $(\text{NH}_4)_2\text{SO}_4$ particles greatly increase the rate of attack. SiO_2 and charcoal purified air have little effect, but charcoal has an enormous effect in presence of traces of SO_2 because of local concentration of the gas. Carbon dioxide has a definite repressive effect on the corrosion of iron under all conditions investigated, especially marked in the presence of $(\text{NH}_4)_2\text{SO}_4$ particles.

1931

1. Relation of the Moisture in Rust to the Critical Humidity.

W. S. Patterson and L. Hebbs. Trans. Faraday Soc., v. 27, 1931, pp. 277-283.

On the assumption that iron rust has a gel structure, the marked effect that rust has in accelerating corrosion can be explained. In humid atmospheres, less than 40 percent saturated, water that is present in the rust is strongly adsorbed by the gel and is held by the considerable force such that it is not free to further corrosion. If the humidity is above this critical humidity, the gel fills with water and the forces that hold the water are lessened at the same time. Though there is but a small increase in the moisture content of the rust at the critical humidity, a much larger amount becomes available to further corrosion.

1929

1. The Atmospheric Corrosion of Iron. W. S. Patterson. J. Soc. Chem. Ind., v. 49, 1929, pp. 203t-206t.

Strips of mild steel and high-carbon steel were suspended in air over KOH. After 30 days the rust effect was negligible in both cases. Similarly over H_2SO_3 the rusting was severe. Over distilled water the rust effect was slow at first, then very rapid and finally slower, with the steel corroding at a greater rate than the iron. Once the strips were covered with rust they were no longer passive to corrosion over KOH. In this phase of the attack the corrosion control appeared vested in the relative humidity rather than in any pollution of the atmosphere. For a non-homogeneous metal surface, the deposition of H_2O , either because of high relative humidity or because of the hygroscopicity of adhering solids, induces corrosion. Patterson partly attributes the corrosion to the ferrite present.

2. The Relative Corrodibilities of Ferrous and Non-Ferrous Metals and Alloys. Part II--The Results of Seven Years' Exposure to Air at Birmingham. J. N. Friend. J. Inst. Metals, v. 42, 1929, pp. 149-155.

Fifty-four bars of ferrous and non-ferrous metals were exposed to air on the roof of the Birmingham Central Technical College for seven years, and an account is given of the 17 non-ferrous bars. The metals examined included tin, lead, nickel, zinc, aluminum, and various coppers and brasses. All resisted corrosion much more efficiently than the wrought irons and carbon steels. Nickel proved less resistant than copper. Aluminum ranked with lead, tin, and stainless steel in offering a very high resistance to corrosion. The influence of arsenic on copper is discussed.

1921

1. A Colloid Theory of the corrosion and Passivity of Iron, and of the Oxidation of Ferrous Salts. J. N. Friend. Trans. J. Chem. Soc. (London), v. 119, 1921, pp. 932-949.

A theory is suggested that:

1. Iron is "noble" or passive towards distilled water in the absence of a catalyst and passes into solution, but only with extreme slowness, owing to the traces of electrolytes that are present.
2. The dissolved iron is probably at first present in a more or less completely ionised ferrous condition, but is rapidly converted into the sol of ferrous hydroxide.
3. This sol then undergoes oxidation by dissolved oxygen into the sol of a higher hydroxide, ferric hydroxide sol being formed under the most favourable conditions, and probably ferrous-ferric hydroxide sol when the supply of oxygen is limited.
4. The higher hydroxide sol now acts catalytically by oxidising metallic iron with relative rapidity and simultaneously undergoing reduction to a lower hydroxide sol, only to be oxidized again as oxygen from the air diffuses towards it.

The theory is tested by determining whether or not the phenomena of corrosion are influenced by such factors as affect the formation, stability, and precipitation of electropositive colloids (e.g., metallic hydroxide sols).

2. Some Observations on the Mechanism of the Increased Corrosion Resistance of Steel and Iron Due to Small Copper Contents. D. M. Buck. Trans. Am. Electrochem. Soc., v. 39, 1921, pp. 109-116.

The evidence presented indicates that the harmful influence of sulfur in steel on corrosion is controlled in some manner by the addition of copper. The structure of the rust film formed is a function of the increased resistance peculiar to copper steel. The difference in

structure may be due to the slower corrosion rate. The corrosion film formed apparently acts mechanically as a protector of the underlying metal.

1920

1. A Review of the Development of Copper Steel. D. M. Buck. Iron Age, October 28, 1920, pp. 1109-1110.

The more important evidence which proves the remarkable influence of copper additions to steel and iron in checking the attack of atmospheric moisture and oxygen is presented. The more general adoption of copper steel in other sections than sheet metal, to which uses it has largely been confined up to the present time, is urged. A discussion of the literature on the effect of copper from the corrosion standpoint is included.

1919

1. The Influence of Very Low Percentage of Copper in Retarding the Corrosion of Steel. D. M. Buck. Proc. American Society for Testing and Materials, v. 19, No. 2, 1919, pp. 224-237.

Previous work by the author indicated that copper in steel in amounts heretofore considered as only traces, materially influences the corrosion rate. In order to obtain further information, two heats of basic open-hearth steel were copperized in varying amounts from approximately 0.01 percent up to 0.25 percent. Sheets and test specimens from the various ingots were exposed to the weather for varying lengths of time, and the paper includes tables of chemical analyses and weight losses, as well as photographs and charts, showing condition of sheets and test specimens after exposure.

The following conclusions have been drawn from the results of this investigation: (1) Very low amounts of copper in steel materially lower the corrosion rate. (2) Steel with 0.03 percent of copper corrodes only 60 to 70 percent as fast as the same steel with 0.01 percent of copper. (3) It has been customary to consider a copper content of any amount under 0.05 percent as a trace, and it may be desirable to reinterpret many corrosion data obtained in work in which the effect of minute amounts of copper has not been taken into account. (4) In order to leave an ample factor of safety, steel to resist atmospheric corrosion should contain not less than 0.15 percent of copper. (5) Copper in amount of 0.12 percent is sufficient to neutralize the influence of sulfur as high as 0.055 percent. (6) Copper in amount of 0.15 percent is sufficient to protect steels even if the sulfur content is considerably higher than normal.

ALUMINUM ALLOYS

1982

1. A Probe for Monitoring Corrosion In Marine Environments. V. S. Agarwala. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 183-192. (Fe82-1)
2. Accelerated Atmospheric-Corrosion Testing. M. Khobaid, F. C. Chang, E. E. Keppler, and C. T. Lynch. Atmospheric Corrosion of Metals, edited by S. W. Dean, Jr., and E. C. Rhea, American Society for Testing and Materials, ASTM STP 767, 1982, pp. 374-394. (Fe82-2)
3. Acid Rain: Impacts on the Natural and Human Environment. Hans C. Martin. Materials Performance, v. 21, No. 1, 1982, pp. 36-39. (Fe82-3)
4. Aluminum Alloy Performance in Industrial Air-Cooled Applications. K. R. Wheeler, A. B. Johnson, Jr., and R. P. May. Atmospheric Corrosion of Metals, edited by S. W. Dean, Jr., and E. C. Rhea, American Society for Testing and Materials, ASTM STP 767, 1982, pp. 116-134.

Air-cooled equipment has an impressive record of performance in industrial cooling applications, particularly in rural-dry environments. At temperatures below the dew point, however, combinations of moisture and contaminants (particularly chlorides and some sulfur compounds) promote severe corrosion on aluminum. Washing the cooling surfaces with some commercial detergents provides a corrosive environment, particularly on areas where drainage collects. Coal dust deposits have caused corrosion of aluminum fins. Marine-humid-industrial locations have caused severe corrosion problems on aluminum air-cooled equipment, particularly when the coolers are at ambient temperatures for extended periods. The results of the domestic survey and available specimens have directed this study principally to aluminum. However, the foreign survey, which is summarized here, provided some insights into the behavior of galvanized steel cooling towers.

5. Atmospheric Corrosion of Bimetallic Structures. V. Kucera and E. Mattsson. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 561-574. (Fe82-6)
6. Atmospheric Corrosion of Fastener Joints. E. Taylor. Extended Abstracts, International Symposium on Atmospheric Corrosion, (October 5-10, 1980, Hollywood, Florida), Electrochemical Society, v. 80-2, 1980, pp. 609-610. (Fe82-7)

7. Atmospheric Corrosion of Large Aircraft: Predicting Damage and Maintenance Requirements. R. Summitt and F. T. Fink. Extended Abstracts, International Symposium on Atmospheric Corrosion (October 5-10, 1980, Hollywood, Florida), Electrochemical Society, v. 80-2, 1980, pp. 603-604.

Maintenance and operational histories of 500 multi-engine jet aircraft were analyzed to determine relative environmental corrosiveness of operational airbases and to assess the variability of maintenance practices. The results were compared with environmental ratings based on weather and pollutant factors. Improvements were made to the reliability of maintenance data by means of a special inspection and data collection program to yield accurate forecasts of corrosion damage and maintenance requirements.

8. Atmospheric Corrosion of Metals Under Moving Conditions. J. D. Talati and B. M. Patel. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 695-704. (Fe82-10)
9. Atmospheric Corrosion Test Results for Metallic-Coated Steel Panels Exposed in 1960. D. E. Tonini. Atmospheric Corrosion of Metals, edited by S. W. Dean, Jr., and E. C. Rhea, American Society for Testing and Materials, ASTM STP 767, 1982, pp. 163-185.

Results of an ASTM-sponsored 20-year exposure of corrugated metallic-coated steel panels at five locations in the United States is reported. A total of 19 panels was placed at each exposure site including at least one specimen from each of six types of continuous galvanizing lines in use when the test was initiated, five sheets galvanized using equipment similar to that used to prepare specimens for a similar test series initiated in 1926, one panel coated with pure aluminum, one panel coated with an aluminum-silicon alloy and one panel coated with terne metal.

The analysis of the galvanized coatings data suggests the presence of non-linear effects in the performance of the coatings. However, it was not possible to establish whether these effects were the result of non-linearities in the coating performance itself or if they were the consequence of uncontrollable external factors which occurred during the exposure period.

The aluminized sheets were found to be essentially without failure at all test locations. In general, coating degradation beyond minor pinholing was not found. The terne-coated sheets evidenced rusting at all except the most aggressive of the test sites. Despite near total coating depletion, none of the test sheets have perforated.

10. Atmospheric Corrosion Testing in Brazil. A. C. Dutra, and R. Vienna. Atmospheric Corrosion, edited by W.H. Ailor, Wiley, New York, N.Y., 1982, pp. 755-774. (Fe82-16)

11. Atmospheric Corrosion Testing in Finland. T. Hakkarainen and S. Ylasaari. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 787-796. (Fe82-17)
12. Atmospheric Corrosion Testing In The Federal Republic of Germany. G. Oelsner. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 797-806. (Fe82-18)
13. Atmospheric Corrosion Testing of Aluminum In Italy. F. Gatto and A. Perrone. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 827-840.

Results of 5 years exposure tests on aluminum and its alloys in the Arenzano and Kure Beach (U.S.A.) marine atmospheres, industrial (Novara), and urban (Milan) environments are reported. It is stated that corrosion by marine atmospheres is considerably affected by test location. In addition, the report provides the results of 9 years exposure to marine and urban atmospheres of alloy 6063 samples having different iron contents and microstructures (fine and coarse), coated with 6.12 and 24 μm anodic films.
14. Atmospheric Corrosion Testing in Japan. T. Fukushima, N. Sato, Y. Hisamatsu, I. Matsushima, and Y. Aoyama. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 841-872. (Fe82-19)
15. Atmospheric Corrosion Testing in Norway. L. Atteraa and S. Haagenrud. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 873-892. (Fe82-20)
16. Atmospheric Corrosion Testing in Southern Africa. B. G. Callaghan. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 893-912. (Fe82-21)
17. Colloid and Surface Phenomena in the Corrosion of Metals. E. Matijevic. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 123-138. (Fe82-28)
18. Corrosion Fatigue Testing of Aluminum in Japan. T. Kurobe. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 983-990.

The investigations on the atmospheric-corrosion fatigue of aluminum in Japan have been reviewed. The studies have revealed that the growth and propagation of cracks in aluminum by fatiguing was remarkably dependent upon the atmospheric pressure. The detailed examinations on the fatigue behavior showed that the mode of slip deformation and the fracture

surface appearance were drastically changed in the range of pressure 10^{-2} to 10^{-3} Torr.

19. Economic Assessment of Pollution Related Corrosion Damage. F. H. Haynie. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 3-18. (Fe82-33)
20. Effect of Atmospheric Pollutant Gases on the Formation of Corrosive Condensate on Aluminum. S. C. Byrne and A. C. Miller. Atmospheric Corrosion of Metals, edited by S. W. Dean, Jr., and E. C. Rhea, American Society for Testing and Materials, ASTM STP 767, 1982, pp. 359-373.

As part of a program to develop predictive methods to estimate the long-term durability of aluminum parts, a methodology was developed to calculate the chemical composition of condensates formed on aluminum exposed to polluted air.

In this study, it is proposed that the maximum concentrations of ionic species in a condensate must be limited by the equilibrium condition established between the dissolved ions and the gases from which they formed.

21. Electrotopography - A New Tool for Corrosion Research. M. Ensanian. Extended Abstracts, International Symposium on Atmospheric Corrosion (October 5-10, 1980, Hollywood, Florida), Electrochemical Society, v. 80-2, 1980, pp. 480-482. (Fe82-36)
22. Evaluation of the Effects of Microclimate Differences on Corrosion. F. H. Haynie. Atmospheric Corrosion of Metals, edited by S. W. Dean, Jr., and E. C. Rhea, American Society for Testing and Materials, ASTM STP 767, 1982, pp. 286-308. (Fe82-39)
23. Ion Chromatographic Analysis of Contaminants on Zinc and Aluminum Surfaces Exposed to a Range of Urban Indoor Environments. G. B. Munier, L. A. Psota-Kelty and J. D. Sinclair. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 275-284.

Water soluble contaminants that accumulate on zinc and aluminum electronic equipment surfaces have been analyzed by ion chromatography. Chloride, sulfate, nitrate, sodium, ammonium, and potassium concentrations have been measured. The ranges of accumulation rates observed for chloride and sulfate are 0.1-1.2 $\mu\text{g chloride/cm}^2/\text{yr}$ on zinc, 0.03-1.0 $\mu\text{g chloride/cm}^2/\text{yr}$ on aluminum, 0.2-2.0 $\mu\text{g sulfate/cm}^2/\text{yr}$ on zinc, and 0.2-1.1 $\mu\text{g sulfate/cm}^2/\text{yr}$ on aluminum. Cities studied include New York, Cleveland, Houston, Council Bluffs (Iowa), Boulder, Colorado Springs, Denver, and Minneapolis.

24. Long-Term Atmospheric Corrosion of Aluminum and Aluminum Alloys. E. W. Skerrey. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 329-352.

Case histories are cited for the use of unprotected aluminum and aluminum alloys exposed in severe environments for periods of around thirty years. Aluminum and aluminum alloys within designation groups 1000 and 3000 to 6000 have performed well in a variety of applications including welded hulls and superstructures, space frames, and cladding. Case histories are cited for the use of anodizing and selected paint systems for long-term aesthetic performance on aluminum.

25. Progress in Atmospheric Corrosion Testing. D. Knotkova, K. Barton and M. Cerny. Extended Abstracts, International Symposium on Atmospheric Corrosion (October 5-10, 1980, Hollywood, Florida), Electrochemical Society, v. 80-2, 1980, pp. 526-528. (Fe82-44)
26. Rapid Methods for Determining Atmospheric Corrosivity and Corrosion Resistance. D. P. Doyle and T. E. Wright. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 227-244. (Fe82-45)
27. Resistance of Galvanized, Aluminum-Coated, and 55% Al-Zn-Coated Steels to Atmospheric Corrosion Involving Standing Water. L. Allegra, N. S. Berke, and H. E. Townsend. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 595-606.

Although most atmospheric testing is conducted under conditions that allow rapid runoff and drying, many applications such as roofing, gutters and culverts require resistance to prolonged immersion in trapped water. Laboratory and atmospheric corrosion tests involving stagnant-water immersion were used to characterize the performance of steel sheets with aluminum, zinc, and Al-Zn coatings. The 55% Al-Zn alloy provides the best protection because it is anodic to steel and resistant to pitting and general dissolution.

28. Stress Corrosion of Metals in the Atmosphere. A. Gallacio. Extended Abstracts, International Symposium on Atmospheric Corrosion (October 5-10, 1980, Hollywood, Florida), Electrochemical Society, v. 80-2, 1980, pp. 581-582. (Fe82-47)
29. The Atmospheric Corrosion Performance of Aluminum-Coated Steels. H. H. Lawson. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 575-594.

The recognized atmospheric corrosion resistance of aluminum led to a search for means to apply it to steel as a protective coating. Various methods, including pack diffusion, electroplating, vacuum vapor deposition, and roll cladding have been used, but the application of hot dipping in the same manner as galvanizing led to economically viable product for widespread application to industrial and commercial roofing and siding. Considerable long-term atmospheric testing data on hot dipped aluminum coated steel will be presented along with actual in-service application

performance of roofing and siding in a wide variety of atmospheric exposures.

30. The Interplay of Weather, Climate and the Durability of Materials, P. W. Brown and L. W. Masters. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 31-50. (Fe82-48)
31. The USAF Corrosion Testing Program and a Corrosion Severity Index Algorithm. R. Summitt and F. T. Fink. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 245-264.

In a paper presented in March 1980 the authors discussed a U.S. Air Force program designed to develop an environmental severity classification for all airbases. Three algorithms were proposed to provide indexes of corrosion severity for three corrosion related maintenance programs. Additional analysis of the atmospheric test results has been completed and a least squares linear regression program has been used to compute slopes. The slopes have been correlated with AFM 66-1 corrosion maintenance data and compared with both the initial corrosion factor algorithm and the three decision-algorithms referred to above. Site-by-site comparisons have been also correlated with other atmospheric test results as reported in the literature.

32. Theoretical and Engineering Principles of Atmospheric Corrosion of Metals. Yu N. Mikhailovskii. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 85-109. (Fe82-52)
33. Thirty (30) Year Atmospheric Corrosion of Aluminum Alloys in France. M. Lashermes, A. Guilhaudis, M. Reboul and G. Trentelivres. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 353-364.

This paper reports the results of long time exposure (15-25 years) of aluminum alloys in the marine atmosphere at Salin-de-Giraud. There were three alloy series (lxxx, 2xxx, and 3xxx), and for each series the influence of composition and metallurgical condition were studied. Only pitting corrosion was generally observed. The sensitivity of the lxxx alloys to pitting decreased in the order: annealed, half and fully hardened. The type 1199 and 3003 alloys showed the best behavior. These tests indicate that aluminum and some alloys can be used safely for long times in marine atmosphere without any protection.

34. Weathering of Aluminum and its Alloys. G. Sowinski and D. O. Sprowls. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 297-328.

The results of an extensive literature search on the weathering of aluminum alloys are presented in this monograph. Theoretical mechanisms are reviewed and the familiar "self-stopping" curves are

described in terms of the relationship $D = A \phi^B$, where D is the measure of corrosion and ϕ is exposure time. A and B are alloy and environment dependent constants. Methods for the investigation of atmospheric corrosion and the various procedures for the assessment of corrosion damage are discussed. Long-term atmospheric corrosion test data are presented for both wrought and cast aluminum alloys. Corrosion rate comparisons are drawn between aluminum alloys and other metals. Galvanic corrosion, crevice effects, and the importance of good design practices also are discussed. Anodized coatings are shown to further enhance the weatherability of aluminum alloys.

1981

1. Acid Rain: Impacts on the Natural and Human Environment. H. C. Martin. Paper No. 114, Corrosion/81 (Toronto, Canada), National Association of Corrosion Engineers, Houston, TX, April 6-10, 1981, 7 pp. (Fe81-1)
2. Corrosion Fatigue of Anodized Aluminum 7075-T73 in Salt Ladened Humid Air. A. T. Funke, D. F. Hasson and C.R. Crowe. Report No. EW-1-81, United States Naval Academy, Division of Engineering and Weapons, Mechanical Engineering Department, Jan. 1981, 53 pp.

Corrosion fatigue of Al7075-T73 anodized by various methods has been measured in salt laden moist air. Principal results are: (1) anodization caused a reduction in fatigue life irrespective of the thickness or type of anodization; (2) a correlation of alumina density with fatigue life was not found; (3) reduction of fatigue life in the environment is attributed to crack growth of microcracks both present and/or initiated in the anodized coating. Details of fatigue environmental chamber and statistical analysis of the data are given in appendices.

3. Practical Experience with an Electrochemical Technique For Atmospheric Corrosion Monitoring. V. Kucera and J. Gullman. Electrochemical Corrosion Testing, ASTM STP 727, edited by F. Mansfeld and U. Bertocci, American Society For Testing and Materials, 1981, pp. 238-255. (Fe81-12)

1980

1. A Model of Atmospheric Corrosion of Metals Allowing for Meteorological and Aerochemical Characteristics. Yu. N. Mikhailovskii, P. V. Strekalov, and V. V. Agafonov. Protection of Metals, v. 16, No. 4, 1980, pp. 308-323. (Fe80-1)
2. A Review of Air Pollutant Damage to Materials. J. E. Yocum and A. R. Stankunas. Draft Report to Environmental Criteria and Assessment Office, Office of Research and Development, U.S. Environmental

Protection Agency, Research Triangle Park, North Carolina, December 1980, 92 pp. (Fe80-2)

3. Corrosion of Metal in Wood Products. A. J. Baker. Durability of Building Materials and Components, ASTM STP 691, edited by P. J. Sereda and G. G. Litvan, American Society for Testing and Materials, 1980, pp 981-993. (Fe80-7)
4. Critical Review of the Available Physicochemical Material Damage Functions of Air Pollution. M. Benarie. Report No. EUR-6643, Comm. Eur. Communities, 1980, 97 pp. (Fe80-8)
5. Pacer Line: An Environmental Corrosion Severity Classification System. R. Summitt and F. T. Fine. AFWL-TR-80-4102 (Part I), Wright Aeronocitical Laboratories, Wright-Patterson AFB, Ohio, August 1980, 121 pp. (Fe80-16)
6. Pacer Line: Experimental Determination of Environmental Corrosion Severity. R. Summitt and F. T. Fine. AFWAL-TR-80-4102 (Part II), Wright Aeronocitical Laboratories, Wright-Patterson AFB, Ohio, June 1980, 28 pp. (Fe80-17)
7. Regional Air Pollution Study: Effects of Airborne Sulfur Pollutants on Materials. F. Mansfeld. NTIS Report PB81-126351, January 1980, 163 pp. (Fe80-18)

1979

1. Atmospheric Corrosion of Metallic Systems. II. Analysis of the Corrosiveness of a Medium at Atmospheric Testing Stations of Comecon Countries Based on the Results of Five-Year Tests on Steel, Zinc, Copper, and Aluminum. K. Barton, D. Knotkova, P. V. Strekalov, V. Kemkhadze, V. Kozhukharov, and A. Szobor. Zashch Met., v. 15, No. 4, 1979, pp. 408-415 (Russian). (Fe79-1)
2. Atmospheric Corrosion Resistance of 55% Aluminum-Zinc Coated Sheet Steel: 13 Year Test Results. H. E. Townsend and J. C. Zoccola. Mater. Perform., v. 18, No. 10, 1979, pp. 13-20.

Steel sheets coated with Galvalume Al-Zn-Si alloy, Zn, or Al were exposed 13 years to rural and industrial environments. The Galvalume coating was several times more durable than conventional zinc coatings. At long exposure times in industrial and rural environments, corrosion rates of the Galvalume coating were comparable to those of conventional aluminum coatings. Only zinc and Galvalume provided edge protection in rural and industrial environments. Corrosion mechanisms are discussed. Corrosion products were analyzed.

1978

1. ASTM Atmospheric Corrosion Testing: 1906 to 1976. W. H. Ailor.
Atmospheric Factors Affecting the Corrosion of Engineering Metals, ASTM STP 646, edited by S. K. Coburn, American Society for Testing and Materials, 1978, pp. 129-151. (Fe78-2)
2. Atmospheric Corrosion Behavior of Aluminum-Zinc Alloy Coated Steel.
J. C. Zoccola, H. E. Townsend, A. R. Borzillo, and J. B. Horton.
Atmospheric Factors Affecting the Corrosion of Engineering Metals, ASTM STP 646, edited by S. K. Coburn, American Society for Testing and Materials, 1978, pp. 165-184.

The influence of the aluminum content of hot-dip aluminum-zinc alloy coatings on their corrosion behavior was studied by means of salt-spray and atmospheric corrosion tests. The objective was to develop an improved aluminum-zinc alloy coating on steel that would be more durable than galvanized coatings and that would be more protective to cut edges and areas of mechanical damage than hot-dip aluminum coatings. The optimum alloy was found to be 55 wt-pct aluminum-zinc. This new alloy coating is 2 to 4 times as corrosion resistant as a galvanized coating of similar thickness. Furthermore, for the galvanic protection of cut edges of sheet in some environments, this coating proved to be superior to aluminum coatings.

3. Atmospheric Corrosion. T. Hakkarainen. Tutkimus Tek., 1978, Nos. 4-5, pp. 46-54 (Finnish). (Fe78-4)
4. Corrosion Prevention With Thermal-Sprayed Zinc and Aluminum Coatings.
F. N. Longo and G. J. Durmann. Atmospheric Factors Affecting the Corrosion of Metals, ASTM STP 646, edited by S. K. Coburn, American Society for Testing and Materials, 1978, pp. 97-114.

This paper presents the results of 19 years' testing, undertaken by the American Welding Society, to evaluate the flame-sprayed zinc and aluminum coatings, sealed and unsealed, applied to low-carbon steel.

Panels were exposed to seawater at mean tide and below low tide levels at two different locations. Panels were also exposed to atmospheric conditions at six different locations including rural, industrial, salt air, and salt spray environments.

The results indicate that low-carbon steel can be protected from the corrosive effects of these environments for 19 years or more by the application of flame-sprayed zinc or aluminum coatings.

5. Deteriorative Effect of Sulfur Pollution on Materials. J. O. Nriagu.
Sulfur in the Environment, Part II: Ecological Impacts, edited by J. O. Nriagu, Wiley, New York, 1978, pp. 1-59. (Fe78-11)

6. Effect of Daily Fluctuations of Humidity and Air Temperature on Moisture Sorption by a Metal Surface and on the Kinetics of Atmospheric Corrosion. P. V. Strekalov, Y. N. Mikhailovskii, and M. V. Danilova. Zashch. Met., v. 14, No. 3, 1978, pp. 243-247 (Russian).*

The effect of atmospheric temperature-humidity dynamics on the thickness of adsorption-moisture film and the corrosion kinetics of aluminum and magnesium under the film were investigated. Depending on the relative humidity, the adsorption layer varied $(1.5 \text{ to } 2) \times 10$ monolayers/24 hr. A relation was established between the corrosion-rate variations and the changes in the physical-chemical parameters of the atmosphere. Temperature was not a determining condition for atmospheric corrosion of metals under the adsorption films of moisture in moderate climate.

7. The Corrosion and Protection of Metals in the Building and Construction Industries. B. G. Callaghan. J. Oil Color Chemists Assoc., v. 61, No. 11, November 1978, pp. 411-418. (Fe78-17)

1977

1. Galvanic Corrosion In the Atmosphere. V. Kucera. Rapp.-Korrosionsinst. No. 16, 1977, 43 pp. (Swedish). (Fe77-9)
2. Study of Atmospheric Corrosion Inhibitors on Metal Surfaces by X-Ray Electron Spectroscopy. A. N. Novitskii, Ya. V. Salyn, and V. I. Nefedov. Zashch. Met., v. 13, No. 2, 1977, pp. 209-212 (Russian). (Fe77-13)

1976

1. Air Pollution Effects on Stress Induced Intergranular Corrosion of 7005-T53 Aluminum Alloy. F. H. Haynie. Stress Corrosion--New Approaches, edited by H. L. Craig, Jr., American Society for Testing and Materials, ASTM STP 610, 1976, pp. 32-43.

Through a statistically designed, controlled environment experiment, it was found that atmospheric levels of sulfur dioxide induce a type of stress-accelerated intergranular corrosion in 7005-T53 aluminum alloy extruded tube material. Varying levels of nitrogen dioxide, ozone, relative humidity, and their interactions (including those with sulfur dioxide) did not cause statistically significant damage in this particular experiment. Some level of stress was necessary to cause this type of attack.

2. Corrosion of High-Alloy Aluminum Alloys Under Atmospheric Conditions. V. D. Kalinin, G. M. Budov, and V. S. Sinyavskii. Zashch. Met., v. 12, No. 5, 1976, pp. 571-575 (Russian).*

Aluminum alloy coupons and clad sheets of D16T and V95T1 were exposed to atmospheric corrosion for 5 years under rural, industrial, and marine conditions. Pitting, segregation, and intergranular corrosion were measured. Pitting corrosion increased with increasing chloride content in the atmosphere but was not affected by sulfur dioxide.

3. Corrosion of Light Metals and Their Alloys in an Atmosphere Polluted With Sulfur Dioxide and With Products of Its Neutralization With Ammonia. B. Mazurkiewicz, J. Banas, K. Bieda, and A. Piotrowski. Zesz. Nauk. Akad. Gorn.-Hutn. im. Stanislaw Staszica, Mat. Fiz. Chem., v. 27, 1976, pp. 115-126 (Polish).*

Aluminum, magnesium, and their alloys, some containing Si, Zn, and Cu, were exposed for >400 days to air containing <0.08 vol. percent SO₂ at a relative humidity of >90 percent. Aluminum and its alloys were corrosion resistant due to a protective film of corrosion products. Magnesium and its alloys were less resistant. Addition of NH₃ to the polluted atmosphere promoted corrosion.

4. Effects of Gaseous Pollutants on Materials: A Chamber Study. F. H. Haynie, J. W. Spence, and J. B. Upham. NTIS Report PB-251580, 1976, 98 pp. (Fe76-5)
5. Effects of Power Plant Emissions on Materials. J. E. Yocom and N. Grappone. Research Corporation of New England, Wethersfield, Connecticut, NTIS Report PB-257539, July 1976, 85 pp. (Fe76-6)
6. Protection Against Atmospheric Corrosion. K. Barton. Translated by J. R. Duncan. Wiley, N.Y., N.Y., 1976, 194 pp. (Fe76-14)

1975

1. Atmospheric Corrosion Investigation of Aluminum-Coated, Zinc-Coated, and Copper-Bearing Steel Wire and Wire Products. V. I. Kelley. ASTM STP 585, American Society for Testing and Materials, 1975, 89 pp.

This atmospheric exposure investigation of aluminum-coated and zinc-coated wire and wire products was conducted by ASTM committee A-5 on Corrosion of Iron and Steel. The data for the 12 years of exposure in the United States and 9 years in England were the basis for this paper. Some of the facts deduced by the data up to 1973 are: (1) The comparison can only be made on the basis of corrosion rates to initial rusting; (2) for aluminum, the light weight coating shows an overall life superior to the

heavy weight of coating; (3) uncoated copper-bearing steel is more resistant than zinc-coated steel (0.5 oz/ft^2).

2. Effects of Graphite Epoxy Composite Materials on the Corrosion Behavior of Aircraft Alloys. P. Fischer and J. J. DeLuccia. Naval Air Development Center, Warminster, Pa., Air Vehicle Technology Dept., Report No. NADC-75031-30, April 1975, 36 pp.

The electrochemical approach was used to show the nature of the galvanic corrosion when graphite-epoxy composite materials are coupled to aluminum and titanium alloys. An open-circuit potential difference of one volt was obtained in 3.5 percent NaCl solution between the composite and 7075-T6, 7075-T651 and 5052-H38 alloys. This potential difference provides a driving force for corrosion and is cause for concern. The Ti-6Al-4V showed a difference of about 0.3 volt for the unpolished as received material. Corrosion current data (zero impedance technique) indicate that aluminum alloys and cadmium plate are much more reactive than Ti-6Al-4V when coupled to graphite-epoxy. This technique provides a means of ranking the severity of this corrosion problem for various aircraft alloys. Flatwise tensile data indicate significant strength losses when graphite-epoxy composite sandwich specimens are exposed to 5 percent salt spray and synthetic seawater plus sulfur dioxide spray environments.

3. Environmental Exposure System for Studying Air Pollution Damage Materials. J. W. Spence, F. D. Stump, F. H. Haynie, and J. B. Upham. NTIS Report PB-240615/5ST, 1975, 46 pp. (Fe75-11)
4. Long-Range Transportation of Air Pollutants and Corrosion Effects. S. Haagenrud and B. Ottar. Proc. 7th Scandinavian Corrosion Conference, 1975, pp. 102-105. (Fe75-12)
5. Outdoor Corrosion Performance of Anodized and Electrolytically Coloured Aluminum for Architectural Use. J. Patrie. Trans. Inst. Metal Finishing, Spring/Conf., v. 53, No. 1, 1975, pp. 28-32.**

The corrosion resistance is reported of Al sheet and Al alloy (6063-AlMgSi) extrusions anodized in H_2SO_4 and coloured with Cu and Ni salts. Results indicate that the use of Ni salts provides a bronze colour having long-term stability whereas Cu salts tend to reduce the corrosion resistance of the anodic film, especially in dark shades.

6. Some Aspects of the Corrosion Resistance of Aluminum Alloys In a Marine Atmosphere. A. Guilhaudis. Anti-Corrosion Methods Mat., v. 22, No. 3, March 1975, pp. 12-16.**

Detailed data are given for a wide range of variously worked and heat-treated Al alloys exposed for up to 10 years at the Salin-de-Giraud (Mediterranean) and other marine sites. Al-Mg compositions were highly resistant to immersion effects and, like the Al-Mg-Si alloys, to salt mist

and spray. In the unwelded states, comparable behaviour was also observed with Al-Zn-Mg compositions. Cold-worked alloys proved as corrosion-resistant as annealed specimens. Results for Al-Cu-Mg and cast alloys, the effects of colour- and orthodox anodizing, and corrosion resistance at an industrial site are also discussed.

7. Sulfur Dioxide and Material Damage. D. G. Gillette. J. Air Pollution Control Assn., v.25, No. 12, December 1975, pp 1238-1243. (Fe75-17)

1974

1. Air Pollution Effects on Catastrophic Failure of Metals. J. Gerhard and F. H. Haynie. Environmental Protection Agency, EPA-650/3-74-009, November 1974, 33 pp. (Fe74-2)
2. Corrosion of Metals in the Atmosphere. W. K. Boyd and F. W. Fink. MCIC Report 74-23, Battelle-Columbus Labs., Metals and Ceramic Information Center, Columbus, Ohio, August 1974, 77 pp. (Fe74-9)
3. Design of a Laboratory Experiment to Identify the Effects of Environmental Pollutants on Materials. J. W. Spence and F. H. Haynie. Corrosion in Natural Environments, ASTM STP 558, 1974, American Society for Testing and Materials, 1974, pp. 279-291. (Fe74-10)
4. Exfoliation Corrosion Testing of 7075 and 7178 Aluminum Alloys-- Interim Report on Atmospheric Exposure Tests. D. O. Sprowls, T. J. Summerson and F. E. Loftin. Corrosion in Natural Environments, ASTM STP 558, American Society for Testing and Materials, 1974, pp. 99-113.

Atmospheric exposures of 18 to 39 months have been completed at seacoast and inland industrial locations to determine the resistance to exfoliation corrosion of specially heat-treated test panels of high-strength aluminum alloys. Two seacoast locations, one at Point Judith, Rhode Island, and another at Daytona Beach, Florida, were selected, together with an industrial location near Chicago, Illinois, to represent the relatively severe atmospheric conditions to which aluminum alloy aircraft structures are subjected in service. The purpose of these tests was to demonstrate the relationship of the performances in the accelerated exfoliation corrosion tests previously evaluated by this task group with those in relatively aggressive natural environments.

The exfoliation performance is being evaluated on test panels heat treated to produce three different metallurgical structures that would be expected to provide a high, low, and medium resistance to exfoliation of both a 7075 alloy extrusion and a 7178 alloy rolled plate. Results obtained thus far are gratifying in that the atmospheric exposures are ranking the test materials in the same relative order as the new ASTM Standard Method of Test for Exfoliation Corrosion Susceptibility in 7XXX

Series Copper Containing Aluminum Alloys (G 34-72, EXCO test). That is, the materials that showed either a high or a low resistance to exfoliation in the EXCO test also showed the same performance in the seacoast atmosphere, and that which showed an intermediate resistance in the EXCO test showed more spotty and a slower rate of exfoliation in the atmospheric exposures.

Exfoliation of the most susceptible items initiated more rapidly (within five months) at the seacoast, but the exfoliation tended to be more uniform at the industrial site. Other factors, such as the climatic conditions at the seacoast, location and exposure position of the test panels are considered.

5. Relationship of Accelerated Test Methods for Exfoliation Resistance in 7XXX Series Aluminum Alloys with Exposure to a Seacoast Atmosphere. B. W. Lifka and D. O. Sprowls. Corrosion in Natural Environments, ASTM STP 558, American Society for Testing and Materials, 1974, pp. 306-333.

Accelerated corrosion tests are necessary and an invaluable aid to research and quality control engineers, provided that the test has adequate discriminatory ability and the test results relate to serviceability of the metal. An inherent problem associated with accelerated exfoliation tests is the definition of different degrees of susceptibility and the interpretation of borderline performances. The concern in the present instance is that truly insignificant exfoliation tendencies may be magnified out of proportion by the very rapid exfoliation tests now being used in materials specifications for exfoliation resistant 7XXX-T7 alloy products.

Correlation of accelerated tests with service environments or the equivalent is necessary, and it is highly desirable that the range of performances observed in the accelerated test be related to a similar range of performances under service conditions. This paper contains the results of relatively long exposures of test panels to the salt atmosphere at a location about 100 yards from a stony beach at Point Judith, Rhode Island, where the corrosive conditions are representative of other very corrosive environments. These extended exposures are of particular interest because they furnish a basis for evaluating indications of borderline susceptibility to exfoliation revealed in the accelerated corrosion tests.

Four- to eight-year exposures to this aggressive seacoast atmosphere have demonstrated the excellent resistance to exfoliation of 7075-T73 and T76 and 7178-T76 products, whereas exfoliation susceptible T6 temper materials displayed considerable exfoliation after short exposures, sometimes after only three to six months. Both the EXCO immersion test (ASTM G 34-72) and the salt spray test (modified ASTM acetic acid salt intermittent spray) developed the same basic type of corrosion that occurred in the seacoast atmosphere. It was shown, however, that the accelerated tests, especially the spray test, tend to magnify slight indications of susceptibility to exfoliation that are of doubtful practical consequence. Suggestions are made for determining more realistic visual acceptance criteria in 7XXX-T7X materials specifications.

6. Seven-Year Exposure at Point Reyes, California. W. H. Ailor. Corrosion in Natural Environments, ASTM STP 558, American Society for Testing and Materials, 1974, pp. 75-81.

This report is concerned with the data obtained from the 7-year Point Reyes, California removals (second exposure). These exposed panels included thirty-nine alloys of eight basis metals of the 1957 program.

Previous reports concerning this program may be found in the Committee B-3 reports in the ASTM Proceedings for 1959, 1961, and 1962, and in the Committee G-1 report (1966 Proceedings).

A number of test panels were lost due to the work of vandals at the Point Reyes test site during the fall of 1962. A fence subsequently erected should protect panels still exposed for future years. Replacements for 7- and 20-year panels for most alloys were exposed on June 12, 1964. The 7-year panels were removed by task group member T. J. Summerson on June 6, 1971 after a total of 2,550 exposure days. The 20-year test panels remain on the racks for subsequent removal.

7. The Economic Damages of Air Pollution. T. E. Waddell. NTIS Report PB-235701, 1974, 156 pp. (Fe74-21)
8. The Mode of Initial Reaction of SO₂ at a Metal Surface. J. R. Duncan and D. J. Spedding. Corros. Sci., v. 14, 1974, pp. 241-249. (Fe74-23)
9. The Use of Weather and Climatological Data in Evaluating the Durability of Building Components and Materials. L. W. Masters and W. C. Wolfe, NTIS Report COM-74-50841/7, August 1974, 102 pp. (Fe74-25)

1973

1. Calculation of Atmospheric Corrosion Rate of Aluminum and its Alloys in Various Climatic Zones According to Meteorological Parameters. Y. N. Mikhailovskii, G. B. Klark, L. A. Shuvakhina, V. V. Agafonov, and N. I. Zhuravleva. Protection of Metals, v. 9, 1973, p. 240.

The purpose of the work was to investigate the effect of meteorological factors (humidity, air temperature, wetting time of metal surface, chemical composition of atmosphere) on the corrosion rate of aluminum and its alloys under natural conditions and to develop engineering methods for calculating the corrosion effects expected on these materials in any climatic zone.

2. Corrosion Caused by Perspiration. G. A. Tret'yakova and V. P. Barannik. Zashch. Metal., v. 9, No. 6, 1973, pp. 715-717 (Russian). (Fe73-9)
3. New Radiofrequency Study of Metal Corrosion in Moist and Dry Gaseous Media. P. V. Strekalov and Y. N. Mikhailovskii. Nov. Metody Issled. Korroz. Metal., 1973, pp. 157-166 (Russian).

The method depends on the decrease in resonance frequency of a quartz platelet with increase in mass. Changes in mass (of the order of 10^{-8} g/cm²) of the metal layer deposited on the quartz film, can be detected as changes in frequency of the order of 1-2 Hz. The experimental application is described. Pure (99.9 percent) aluminum was coated on quartz and adsorption of H₂O was studied for different pressures of H₂O vapor (P) above it. Adsorbed H₂O increases with P and the rate of adsorption is maximum in the first 10-15 minutes. From the adsorption isotherm (frequency shift versus P), the weight of a monolayer is calculated. This indicates that the actual surface of aluminum is 30 times the apparent geometric surface. In an atmosphere of 93 percent humidity, Mg adsorbs H₂O and also forms oxide. Rate of oxide formation was high in the first hour, reaching a thickness of 5 Å and later becomes low and approximately constant.

4. The Role of Aerobic Bacteria in Metal Corrosion. J. Brison. Corrosion, Traitements, Protection, Finition, v. 21, No. 4, 1973, pp. 242-247 (French). (Fe73-23)
5. Weathering Protection of Aluminum by Varnish. Materiaux et Techniques, v. 61, No. 2, 1973, pp. 46-50 (French).

Various air-drying methacrylic varnishes are suggested. The surface preparation of aluminum, varnish application by different methods, thickness of film and drying are described and results of test in urban and sea atmospheres are presented.

1972

1. Composition of the Atmospheric Corrosion Products of Aluminum. I. A. Efimov, B. N. Rybakov, L. A. Knizhenko, G. V. Maslova, and U. Y. Kharitonov. Zashita Metallov, v. 8, No. 5, 1972, pp. 580-583 (Russian).

The literature gives much information on the phase composition of the atmospheric corrosion products of aluminum and its alloys, but in most cases it is conflicting. This due largely to the fact that field tests performed in different climatic and meteorological conditions do not take account of the true length of the corrosion process or the different degrees of atmospheric pollution by corrosive gases. We have made an attempt to determine the phase composition and thermal stability of the atmospheric corrosion products of aluminum under various field test conditions. Specimens of A-7 aluminum, obtained by continuous casting were investigated. The climatic and meteorological characteristics of the test regions were assessed from the wetting times of the metal surfaces. The atmosphere of the test regions was contaminated by sulfur dioxide, the concentration of which was measured monthly by the linear-colorimetric method.

2. Corrosion of Copper, Aluminum, and Zinc Alloys in a Sulfur Dioxide Atmosphere. S. Kopczynski. Ochrona przed Korozja, v. 15, No. 6, 1972, pp. 149-154 (Polish).

A general introduction to the influence of atmospheric SO_2 on the corrosion of different kinds of metals is followed by the preparation of samples, their location, and methods of testing (visual effects, microscopic examination). The results of investigations carried out in controlled SO_2 concentrations were as follows: copper and its alloys are corroded about 15 to 20 times more than aluminum alloys; zinc alloys are corroded 10 times more than aluminum, but are 2 times better than copper alloys.

3. Exfoliation Corrosion of Aluminum Alloys. S. J. Ketcham and I. S. Shaffer. Localized Corrosion--Cause of Metal Failure, ASTM STP 516, American Society for Testing and Materials, 1972, pp. 3-16.

This paper is a general review of the subject of exfoliation corrosion of aluminum alloys summarizing both published and unpublished work. Present thinking on mechanisms is presented. Susceptible alloys and the corrosive environments in which exfoliation occurs are discussed, as well as effect of varying degrees of exfoliation on static and dynamic fatigue strength of 7075-T6 and on life of an actual aircraft structure. Protective coatings and special heat treatments to minimize exfoliation are discussed.

4. Kinetic Study of the Uptake of Sulfur Dioxide by Aluminum. D. J. Spedding. Br. Corros. J., v. 7, No. 6, 1972, pp. 281-284.

The laboratory investigations were of S-35 SO_2 in atmospheric concentrations on UKAEA foil. Uptake was always linear and strongly dependent on humidity. The humidity dependence was probably related to the equilibrium between gas-phase water and Al-surface water. The fraction of sorbed- SO_2 desorbed when the SO_2 partial-pressure was reduced and increased with decreasing humidity. Sulfur dioxide in aqueous phase may be oxidized to sulfate, which produces free protons. This acidic solution may attack the aluminum protective layer. When the surface is saturated with water, sorbed SO_2 probably moves into the aqueous phase and is oxidized to sulfate. It is most likely that freshly exposed aluminum takes up less SO_2 than weathered aluminum as corrosion increases the surface area. This would enable more water to be held and provide increased sites for SO_2 sorption. The corrosion rate probably increases until leveling off when the surface area has become constant.

5. Survey on the Metal Corrosion by Air Pollution: Effect of Glauber's Salt on Metals. T. Nagano, A. Hattori, T. Nagai, Y. Ukishima, Y. Nakai, and I. Iwasaki. Shizuoka-ken Eisei Kenkyusho Nenpo, No. 16, 1972, pp. 217-226 (Japanese). (Fe72-18)

6. The Influence of the Relative Humidity and Corrosion Products on the Adsorption of Sulfur Dioxide on Metal Surfaces. T. Sydberger and N. G. Vannerberg. Corrosion Science, v. 12, No. 10, 1972, pp. 775-784. (Fe72-22)

1971

1. Atmospheric Corrosion of Metals. M. Arpaia. Atti Not. Assoc. Ital. Metall., v. 26, 1971, pp. 363-367 (Italian). (Fe71-5)
2. Atmospheric Tests. S. K. Coburn. Chapt. 17 in Handbook on Corrosion Testing and Evaluation, edited by W. H. Ailor, Electrochemical Society, Corrosion Monograph Series, J. Wiley, N.Y., N.Y., 1971, pp. 475-505. (Fe71-6)
3. Corrosion by Atmospheric Sulfur Dioxide. D. J. Spedding. Australasian Corros. Eng., v. 15, No. 8, 1971, pp. 27-36.

Ten-year corrosion data for aluminum and five alloys in rural, industrial, and marine atmospheres (mils/year penetration and percentage tensile-strength loss per year) are tabulated. The rate for aluminum in industrial atmospheres is seven times that in rural conditions. Laboratory work has shown that SO_2 is absorbed on the surface. The total amount increases markedly with increased humidity. Sulfuric acid is formed, causing acidic destruction of the protective film. Field tests have shown a 3.5-fold increase in corrosion rate for relative humidity greater than 80 percent. Alloying with Mg, Mn, and, to some degree, silicon reduces the aluminum atmospheric corrosion rate, particularly in a marine environment, but Cu and Zn increase the corrosion in marine and industrial atmospheres.

4. Corrosion of Metals by Sulfur Dioxide. G. K. Singhanian, B. Lal, and B. Sanyal. Labdev. Part A, v. 9, No. 3 & 4, 1971, pp. 214-216. (Fe71-10)
5. Mechanism of Exfoliation (Layer Corrosion) of Aluminum--5% Zinc--1% Magnesium. E. Mattsson, L. O. Gullman, L. Knutsson, R. Sundberg, and B. Thundal. Brit. Corrosion J., v. 6, No. 2, March 1971, pp. 73-83.

The electrochemical properties of the phases occurring in the alloy in the naturally-aged and artificially-aged conditions were investigated. A saturated calomel half-cell was used as a reference electrode and a platinum sheet as a counter electrode. The working electrode consisted of a disc of the alloy or the single phase to be studied. The electrolyte was an aerated aqueous solution of 0.5M NaCl and 10^{-4}M AlCl_3 using 0.1M HCl or 0.1M NaOH for adjustment to pH 3. The open-circuit potential was measured when the working electrode had been in contact with the electrolyte for 5 minutes. Polarization runs were performed by changing

the electrode potential step-wise and anodic and cathodic polarization curves were determined. In the naturally-aged alloy the attack was confined to lamellar zones caused by galvanic corrosion cells. Increase in the Fe, Mn, and Si content decreased resistance to exfoliation. In the artificially-aged condition the alloy was not prone to exfoliation but showed a type of general attack. The zone next to a weld bead became resistant to exfoliation on post-weld artificial aging, but this was not the case for the zone at some distance from the weld bead.

6. Metal Coatings on Steel at Lighthouse Beach, Lagos. J. F. Stanners. Brit. Corrosion J., v. 6, No. 5, Sept. 1971, pp. 211-215. (Fe71-17)
7. Resistance to Corrosion of Aluminum Coatings in Atmospheric Conditions, Particularly in Polluted Atmospheres. V. Vesely. Soudage Tech. Connexes, v. 25, No. 5-6, 1971, pp. 243-246 (French).

Corrosion tests were made on aluminum-coated ferrous metals which had been exposed to several corrosive atmospheres to which a number of chemical compounds had been added as pollutants. Of the 7 different aluminum coatings tested (99.85 percent aluminum; 99.5 percent aluminum; 99.0 percent aluminum; AlMg; AlMn; AlMgMn; AlMgSi) the 99.5 percent aluminum coating showed maximum corrosion protection at a coating thickness of 150 to 300 μm .

8. Technical-Economic Evaluation of Air-Pollution Corrosion Costs on Metals in the U.S. F. W. Fink, F. H. Buttner, and W. K. Boyd. NTIS Report PB-198453, February 19, 1971, 149 pp. (Fe71-25).

1970

1. Accelerated Atmospheric Corrosion Tests in Polluted Air. Mild Steel and Aluminum in Sulfur Dioxide Environment. S. Yamasaki and Y. Yokoi. Boshoku Gijutsu, v. 19, 1970, pp. 335-339 (Japanese). (Fe70-1)
2. Corrosion of Building Materials. A. Valeriana de Seabra and M. Cravo. Tecnica (Lisbon), v. 32, 1970, pp. 493-512 (Portuguese). (Fe70-6)
3. Effect of Chloride and Sulfate Ions on Oxide Film Growth on Aluminum Immersed in Aqueous Solutions at 25°. H. P. Godard and E. G. Torrible. Corros. Sci., v. 10, No. 3, 1970, pp. 135-142.**

The surface film growth was studied on 99.98 percent aluminum in high-purity water containing 0 to 1,000 ppm SO_2 and 0 to 1,000 ppm Cl^- , either alone or mixed. Film growth in low concentrations of SO_4^{2-} was dependent both on the area of metal exposed and on the SO_4^{2-} concentration, film growth in the solution being inversely proportional to the SO_4^{2-} concentration per unit surface area; this was expected on the basis of a simple "selected site" theory for the $\text{Al}/\text{H}_2\text{O}$ reaction, the inhibiting

effect of SO_4^{2-} being due to its selective adsorption at these sites. However, the rate decrease and decreased extent of film formation coupled with increased induction period in the presence of SO_2 plus increased pH on film formation require the amplification of this simple theory. An exchange hypothesis is used to rationalize the results by assuming that in high purity water, OH ions substitute for O^{2-} in the oxide film lattice, that film growth is dependent on substitution of OH^- for O^{2-} ions occurring at "selected sites" on the oxide/ H_2O interface, and that the substitution or exchange of ions is slow and hence rate determining.

4. Inquiry Into the Economic Effects of Air Pollution on Electrical Contacts. R. C. Robbins. SRI Project PSU-7345, Final Report, Stanford Research Institute, April 1970, 39 pp.

A significant part of the total cost of air pollution is directly related to the effects of air pollution on materials. The National Air Pollution Control Administration wishes to analyze this cost, and one of the areas of particular interest is the effect of air pollution on electrical contacts. These devices have a special importance because they are components of extensive communications, computer, and instrumentation systems. The highest degree of reliability and performance is required from electrical contacts to obtain satisfactory overall operation in these systems.

The specific goal of this study was to survey, identify, and document problems of economic significance caused by air pollution in the utilization and operation of electrical contacts and other electrical devices. If air pollution does cause problems, they were to be determined and analyzed by searching the literature, by consulting with experts in the field of electrical contact technology, and by consultation with electrical engineers, manufacturers of electrical contacts, and users of electrical devices.

5. Metallic Coatings for the Protection of Mild Steel From Corrosion at Ambient Temperatures -2. Aluminum Coatings. C. Davies and N. J. Hanford. Corrosion-Anti-Corrosion, v. 17, No. 7, 1970, pp. 20-22.

When exposed to the atmosphere, fresh aluminum rapidly forms an impervious oxide film of aluminum, about 10^{-6} mm thick. An increase in weight/time curve becomes parallel with the time axis after only a few days. From comparison of the standard electrode potentials of aluminum and iron it would be expected that aluminum should exert better sacrificial protection than zinc. However, in practice the protection of steel by this mechanism is limited. This can be explained because the insulating oxide film formed is more noble than aluminum itself, and hence restricts electrochemical protection of bare steel at cracks and pores in the coating.

The extent of sacrificial protection depends upon the area of steel exposed and upon the environment. In atmospheres containing a high chloride concentration, which destroys the oxide film, appreciable cathodic protection occurs. In urban and rural areas where the oxide film is not attacked, practically no galvanic protection occurs.

6. Reaction Between SO_2 and Wet Metal Surfaces. N. G. Vannerberg and T. Sydberger. Corrosion Science, v. 10, 1970, pp. 43-49. (Fe70-11)
7. Systems Analysis of the Effects of Air Pollution on Materials. R. L. Salmon. NTIS Report PB-209192, January 15, 1970, 196 pp. (Fe70-13)
8. The Weathering and Performance of Building Materials. J. W. Simpson and P. J. Horrobin, eds, Medical and Technical Publishing Co. Ltd., 1970, 277 pp. (Fe70-17)

1969

1. A Study of Atmospheric Corrosion of Semifinished Products Made from Aluminum Alloys. G. M. Budov. Proc. 3rd Intern. Congr. on Metallic Corrosion, Moscow (1966), Swets-Zeitlinger, Amsterdam, Holland, v. 4, 1969, pp. 445-453.

Investigations have been conducted into the behavior of eight aluminum alloys in five typical atmospheric zones of the USSR. The most corrosive atmospheres proved to be those of the North Sea and the industrial atmospheres characterized by the highest content of halogen ions. Concentration of corrosive contaminants in the air proves to be more important than the duration of the period the film of moisture stays on the surface of the specimens. The high-alloyed aluminum alloys (AK6T1, B95T1, and others) have displayed a tendency towards corrosion cracking while some of them have also been characterized by exfoliation corrosion.

2. Aluminum Corrosion at Urban and Industrial Locations. W. H. Ailor, Jr. Proc. American Soc. Civil Engr., Journal of the Structural Division, October 1969, pp 2141-2160. (Fe69-21)
3. Calculation of Moistening and Metallic Corrosion in Atmospheric Environment. A. I. Golubev and M. Kh. Kadyrov. Proc. 3rd Intern. Congr. on Metallic Corrosion, Moscow (1966), Swets-Zeitlinger, Amsterdam, Holland, v. 4, 1969, pp. 522-531. (Fe69-24)
4. Corrosion of Aluminum Alloys in Corrosive Media. M. I. Subbotkin, I. A. Efimov, and N. G. Smetanina. Zashch. Korroz. Stroit. Konstr. Povysh. Ikh Dolgovechnosti, 1969, pp. 133-145.**

The endurance of the alloys was considered for more intense corrosive atmospheres, viz. SO_2 , HCl , NO_2 , Cl_2 , NH_3 , CS_2 , and H_2S , as well as for industrial construction. Alloys tested were representative of the Mg, Mn, Mg-Si, and Cu systems not containing >5-7 percent of the principal alloy constituent. The differential penetration speed $dP/dT(10^{-4} \text{ mm})$ gave similar results against initial times of 6-12 months, indicative of progressive linear increase of protective effect by the corroded layer,

further modified by a horizontal or vertical orientation of the sample. Exception was shown in corrosion speed by SO_2 after 18 months, but especially by $\text{HCl} + \text{Cl}_2$ after 6 months, with higher initial rates of 500-2000 units; in the latter case a multiplication of microcathodes and disruption of protective layers has been suggested. With individual alloy variance, the corrosion resistance increased in the systems Al-Cu-Mg, Al-Mg-Si, Al-Mn, and Al-Mg. Clearly it became important to specify an alloy type according to the atmospheric conditions, and especially with large amounts of SO_2 or HCl , to guard against possible condensation.

5. Corrosion in the Atmosphere. P. Atterby. NTIS Report N71-26259 November 1969, 9 pp (Swedish). (Fe69-25)
6. Corrosion of Aluminum and Its Alloys in Air, Gases, and in Liquids. R. B. Mears, M. Cigdemoglu. Demir Celik, v. 18, No. 11, 1969, pp. 323-328 and No. 12, 1969, pp. 354-357 (Turkish).**

Corrosion of pure and alloyed aluminum in liquids, air, and gases is studied. Results obtained in liquids show that the oxygen concentration has no influence on aluminum alloys which are more sensitive to the temperature of the media, the maximum rate of reaction being observed at 70 to 80°. This rate does not depend on the pH, but highly on the types of ions present. For example, aluminum alloys are slightly attacked by weak solutions of HCl , H_2SO_4 , and HNO_3 . Alloys without copper resist sea and condensed water and generally organic acids at room temperature. But the corrosion rate is very high with NaOH or KOH of concentration >0.01 percent. Inorganic salt solutions with a pH of 5-8.5 have no effect on aluminum alloys, which are, however, attacked by chloride or mercury ions. Aluminum is anodic in many solutions. Therefore, contact with copper or copper alloys causes an intense galvanic effect. Aluminum is not attacked by fused salts under normal conditions or organic solutions without chloride or metallic ions. Corrosion resistance of underground aluminum alloys depends on the climate and the earth composition. These alloys, except those containing copper, are highly resistant to atmospheric corrosion.

7. Painting of Metal Sprayed Structural Steelwork--Report on Conditions Specimens after Five Years' Exposure. J. F. Stanners and K. O. Watkins. Australasian Corrosion Eng., v. 13, No. 10, October 1969, pp. 7-17. (Fe69-34)
8. Protection of Steel in the Atmosphere by Sprayed Metallic Coatings. S. Klemantaski and J. F. Stanners. Proc. 3rd Intern. Congr. on Metallic Corrosion, Moscow (1966), Swets-Zeitlinger, Amsterdam, Holland, v. 4, 1969, pp. 509-521.

As part of a wide research on the protection of steel by metallic coatings, the performance of the two main classes of sprayed coatings, aluminum and zinc has been evaluated by exposure testing of flat

specimens. The coating thickness on both faces was nominally 3 mils and specimens were exposed at 45° to the vertical, facing south.

For the aluminum coatings the exposure atmospheres were urban-industrial and semi-rural and the effects studied included aluminum purity, alloying with 5 percent zinc, method of deposition, atmosphere in which deposition was carried out and the presence of gaps of two widths in the coating. For the zinc coatings, only an urban-industrial exposure atmosphere was used, and the effects studied included alloying with 5 percent aluminum and the presence of gaps of two widths in the coating. In addition to the usual methods of inspection, the scanning electron microanalyzer has been used.

The main general conclusion for the range of conditions covered in the investigation is that aluminum coatings last well in both rural and urban-industrial atmospheres. The coatings last better on exposed rather than sheltered surfaces (in contrast to zinc), and are not greatly influenced by the purity of the aluminum or the method of its application.

9. Rapid Determination of Corrosivity of an Atmosphere to Aluminum.
D. P. Doyle and H. P. Godard. Proc. 3rd Intern. Congr. on Metallic Corrosion, Moscow (1966), Swets-Zeitlinger, Amsterdam, Holland, v. 4, 1969, pp. 429-437.

The paper deals with the use of the wire-on-bolt test method for rapid determination of corrosivity of an atmosphere to aluminum. Results are obtained in only three months and the specimens require little time and materials to prepare and examine.

Atmospheric corrosivity indices (for aluminum) were measured at 39 locations in 10 countries in marine, industrial and rural atmospheres. The variation in atmospheric corrosivity with season of the year was determined at four locations. The influence of distance from the sea on marine atmospheric corrosivity was determined at three widely separated parts of the world.

Finally, corrosion experience obtained with actual and test lines of steel-cored aluminum electrical power cables, in a number of marine locations, is correlated with atmospheric corrosivity indices determined at the same locations by the wire-on-bolt method.

1968

1. Atmospheric Corrosion of Aluminum and Its Alloys: Results of Six-Year Exposure Tests. V. E. Carter. Metal Corrosion in the Atmosphere, ASTM STP 435, American Society for Testing and Materials, 1968, p. 257-270.

Results of atmospheric corrosion tests on four aluminum alloys at five sites in Great Britain showed that corrosion, in the form of pitting, increased with atmospheric pollution. Corrosion/time curves became parallel to the time axis within two years at mild sites but at polluted industrial sites had not done so in six years. Aluminum alloys were more heavily attacked than high-purity aluminum, and a pure aluminum cladding gave considerable protection to an aluminum-copper-magnesium alloy.

2. Atmospheric Exposure of Light Metals. S. M. Brandt and L. H. Adam. Metal Corrosion in the Atmosphere, ASTM STP 435, American Society for Testing and Materials, 1968, pp. 95-128.

An evaluation is given of the effects of exposure on the tensile strength of specimens of cast, wrought, and clad aluminum alloys and cast and wrought magnesium alloys exposed at 5 different sites over the United States for a period of 10 years. Aluminum casting alloys, whether sand or permanent mold cast, show the greatest loss in tensile strength when exposed to marine atmospheres. Aluminum cast alloys containing 3 to 5 percent copper showed the greatest loss in tensile strength, most of the loss occurring in the first 3 years. Alloys with 6 percent zinc showed little loss of tensile strength while inclusion of magnesium leads to easier corrosion. Wrought aluminum alloy sheet panels, including one of them containing 6 percent zinc showed a loss in tensile strength. Both riveted sheet panel and unriveted sheet panel aluminum alloys undergo similar effects. Wrought magnesium alloys showed a loss of tensile strength for all exposure sites, the greatest loss being in the New York site. Plate and extended bar specimens with increased section thickness resist corrosion to a greater extent. Magnesium alloys, cast and wrought, showed greater resistance to loss in tensile strength than aluminum alloys.

3. Atmospheric Exposure of Nonferrous Metals and Alloys--Aluminum: Seven Year Data. F. L. McGeary, T. J. Summerson, and W. H. Ailor, Jr. Metal Corrosion in the Atmosphere, ASTM STP 435, American Society for Testing and Materials, 1968, pp. 141-173.

This report describes the results of weathering tests on 34 wrought aluminum alloys exposed seven years at four ASTM sites in the United States. Also included, for comparison, are data on three additional aluminum alloys exposed six years at five sites in England.

The British industrial atmosphere exposures at Sheffield and London were found to produce the most corrosion, particularly on the sheltered sides of these panels which were exposed at an angle of 30 degrees from the horizontal. The self-limiting corrosion characteristics were observed on weather surfaces at all test sites in both countries.

The test will be continued and again reported after twenty years, as was the case in a previous ASTM B-3 test (ASTM STP 175) on older aluminum alloys.

4. Atmospheric Stress Corrosion Testing of Aluminum Alloys. H. B. Romans and H. L. Craig, Jr. Metal Corrosion in the Atmosphere, ASTM STP 435 American Society for Testing and Materials, 1968, pp. 61-82.

Results are given for stress corrosion studies carried out on a number of aluminum alloys. Testing was done at Aruba, Netherlands Antilles, Kure Beach, North Carolina, and Richmond, Virginia. These sites provided environments that ranged from tropical marine to mild industrial. Failure times are compared with laboratory and service results. One aim was to study the effect of prolonged aging at ambient temperatures. In aluminum-magnesium alloys this aging may produce a metallurgical structure

which makes these alloys subject to stress corrosion cracking. Specimens aged at higher temperatures do show this response in laboratory and atmospheric tests. From these accelerated data Arrhenius plots predict these alloys should become susceptible within two to five years if aged at ambient temperatures. However, test results do not bear this out. It is possible to draw erroneous conclusions from only one type of test. For at least one alloy, the rate of failure is much more rapid in the atmosphere than in an accelerated laboratory test. This has been attributed to an interaction between specimens tested in a communal solution. In conclusion, either a laboratory or an atmospheric test is, in itself, insufficient to characterize the stress corrosion behavior of an engineering material. These two tests give data that are complimentary instead of supplementary. Both types are necessary to evaluate the potential hazards of a material having some degree of stress corrosion susceptibility.

5. Corrosion of Metals by Aqueous Solutions of the Atmospheric Pollutant Sulfurous Acid. W. McLeod and R. R. Rogers. *Electrochem. Technol.*, v. 6, No. 7-8, July-August 1968, pp. 231-235. (Fe68-3)
6. Increased Connector Contact Reliability. M. Ball, F. H. Hardie and E. J. Struckus, *The Electronic Engineer*, March 1968, pp. 82-85.

One of the penalties of modularizing a digital system is that more external connectors are needed, since every module requires its own connector. These connectors severely limit the attainable reliability.

Recently, we conducted environmental tests to determine which properties of electrical contact materials could adversely affect reliability. The tests were performed for over a year at several test sites. Relative humidity at these sites varied from around 10% to over 80%. Measured airborne contaminants included various amounts of NO₂, HF, NH₃, SO₂, O₃, Cl₂ and H₂S. Ambient temperatures varied over a range from 60° to 100°F.

7. Investigations of the Corrosion-Causing Properties of Volatile Acids and Anhydrous Acids. E. Iaengle. *Eidgenoessische Technischen Hochschule, Zurich, Switzerland*. Ph.D. Thesis, 1968, 43 pp. (German). (Fe68-11)
8. Performance of Aluminum Alloys at Other Test Sites. W. H. Ailor, Jr. *Metal Corrosion in the Atmosphere*, ASTM STP 435, American Society for Testing and Materials, 1968, pp. 285-307.

Data covering a 7-year period are presented on the corrosion behavior of 11 aluminum alloys at 4 test sites. A decrease in corrosion rate occurred for all alloys after the second year. Depth of pitting decreased with time, and slight increases in depth were noted between the second and seventh years. The industrial site was most corrosive, followed by the moderate industrial, coast marine, and rural marine atmosphere in the order of decreasing severity. The value of cladding basic alloys such as 3003 and 6861 was demonstrated. Maximum pit depth were 14.7 mils for the

aluminum-copper alloy, 10 mils for the aluminum-magnesium alloy, 5.2 mils for the aluminum-magnesium-Si alloy, and 6.3 mils for high-purity aluminum.

9. Resistance of Aluminum in Polluted Atmospheres. E. Mattsson. Tekn. Tidskr., v. 96, No. 38, October 1968, pp. 767-770.

The increasing atmospheric pollution with sulfur compounds in Western Europe is discussed and the advantages of aluminum in resisting atmospheric corrosion are illustrated under various atmospheric conditions in different countries.

10. The Effect of Initial Weather Conditions on the Atmospheric Corrosion of Aluminum and Its Alloys. V. E. Carter and H. S. Campbell. Metal Corrosion in the Atmosphere, ASTM STP 435, American Society for Testing and Materials, 1968, pp. 39-42.

Weight losses for specimens of aluminum alloys exposed for one year to moderately severe industrial and marine atmospheres were similar for groups of specimens put out initially in winter or summer. The depth of pitting on those put out in the winter was, however, from 1-1/2 to 2-1/2 times as great as on those put out in the summer. The difference is explained by the specimens exposed in winter remaining covered with a film of moisture for a greater proportion of the time during their first few weeks or months on test. It is recommended that, when comparing the atmospheric corrosion resistance of aluminum alloys, tests should be started both in summer and in winter.

1967

1. Corrosion by Air Pollution. J. R. Goss. Proc. Annu. Conf., Nat. Soc. Clean Air, No. 34, 1967, pp. 75-92. (Fe67-4)
2. The Sulfur Dioxide-Repellent Action of Aluminum Exposed to the Influence of the Atmosphere. G. Schikorr. Aluminum, v. 43, No. 2, 1967, pp. 108-110.**

Aluminum sheets (area 100 cm²), exposed to the natural atmosphere for 0.5 to 2 years lost 1.6 to 5.4 mg in weight, and less than 1 mg of sulfur dioxide was absorbed by the metal surface. Steel under similar conditions lost 1.1 to 4.1 g in weight and absorbed 22 to 55 mg of sulfur dioxide. The resistance of aluminum is due to its low sulfur dioxide absorption, probably because the oxide or hydroxide coating on its surface is only weakly alkaline.

3. Weathering of Aluminum--Atmospheric Testing of Aluminum Alloys. F. L. McGeary, E. T. Englehart, and P. J. Ging. Matls. Protection, v. 6, No. 6, June 1967, pp. 33-38.

Performance data on aluminum alloys exposed to the atmosphere for 30 years at Point Judith, Rhode Island and New Kensington, Pennsylvania are presented. Eighty years of service data from points throughout world are reported. This paper updates previous papers on performance of aluminum in various atmospheric conditions.

1966

1. Atmospheric Corrosion of Metals at Bhavnagar. V. S. Rao. Indian J. Technol., v. 4, No. 5, 1966, pp. 159-161. (Fe66-3)
2. Atmospheric Corrosion of Steel, Zinc, Cadmium, Copper, and Aluminum in Different Coastal and Continental Regions. G. K. Berukshtis and G. B. Klark. Corrosion of Metals and Alloys, Collection No. 2, Israel Program for Scientific Translations, Jerusalem, 1966, pp. 281-297. (Fe66-4)
3. Corrosion Behavior of Salt Powder Towards Various Metals. A. Bukowiecki and B. G. Joshi. Schweiz. Arch. Angew. Wiss. Tech., v. 32, No. 2, 1966, pp. 42-54. (Fe66-5)
4. How Atmospheric Conditions Can Corrode Refinery Equipment. P. W. Sherwood. Erodell Kohle (Hamburg), v. 19, No. 4, April 1966, pp. 289-290 (German). (Fe66-7)

1965

1. Atmospheric Corrosion of Steels Related to Meteorological Factors in Japan. III. Results of Weathering Tests Conducted on Metallic Coatings for 3 Years. K. Oma, T. Sugano, T. Ueki, and Y. Hirai. Boshoku Gijutsu, v. 14, No. 3, 1965, pp. 103-108 (Japanese).

Weathering tests on metallic coatings were made for 3 years in 7 typical districts. The specimens were mild steel plates coated with various metals by electroplating, metallizing, or hot dipping, and were exposed to the atmosphere. Their corrosion resistances were compared under the environmental peculiarities of those districts. The following metallic coatings were particularly resistant to weathering in all the districts. Electroplating with zinc, zinc with chromate treatment, or cadmium metallizing with zinc or aluminum; hot-dipping with zinc or aluminum.

2. Atmospheric Corrosion Products of Some Commercial Metals. H. J. Meyer. Korrosion, No. 17, 1965, pp. 44-52 (German). (Fe65-3).

3. The Significance of Sulfur Dioxide in the Atmospheric Corrosion of Metals. G. Schikorr. Korrosion, No. 17, 1965, pp. 27-34 (German). (Fe65-20)

1964

1. The Influence of Sulphur Dioxide on the Atmospheric Corrosion of Metals. G. Schikorr. Werkst. Korro., v. 15, No. 5, 1964, pp. 457-463.

1963

1. Galvanic Corrosion Behavior of Aluminum in the Atmosphere. H. P. Godard. Materials Protection, v. 2, No. 6, 1963, p. 38.

Wire-on-bolt test assemblies were used to determine galvanic corrosion behavior of aluminum in contact with eight other metals when exposed to various atmospheres. Test procedure and environments at sites are given. The paper describes method of determining corrosion loss due to galvanic corrosion. Tabular data summarizes test results. Results also are given on crevice corrosion behavior of aluminum in the atmosphere.

2. Ten-Year Weathering Data on Aluminum Alloys. W. H. Ailor, Jr. and F. M. Reinhart. Mater. Protect., v. 2, No. 6, 1963, pp. 30-31, 33, a 36.

The procedure used to evaluate corrosion resistance of various aluminum alloys to urban and marine atmospheric exposures is outlined. Effects of corrosion on mechanical properties of the alloys are discussed, as well as pit depths. Corrosion rates on aluminum level off after about 2 years exposure and remain relatively constant. Corrosion resistances of various tempers of the same alloy showed little variation.

1962

1. Aluminum Alloys Corrosion Behavior in an Industrial Environment. F. F. Booth and K. G. Latimer. Corrosion Technology, v. 9, No. 11, 1962, pp. 315-320. (Fe62-1)
2. Atmospheric Corrosion by Electrolyte Nuclei. B. Sanyal and D. V. Bhadwar. J. Sci. Industr. Res., v. 21D, 1962, p. 243. (Fe62-2)
3. The Possibilities of Increasing the Resistance of Steel Against Atmospheric Corrosion. K. Barton. Intern. Symp. Anti-Corrosion Protect. Bratislava, v. 1, 1962, 8 pp. (Fe62-8)

1961

1. Corrosion in Buildings. P. J. Sereda. Caradiar Building Digest, Report No. CBO-20, August 1961, 4 pp. (Fe61-5)
2. Effect of Nitrogen Tetroxide on Metals and Plastics. C. W. Alley, A. W. Hayford, and H. F. Scott, Jr. Corrosion, v. 17, No. 10, October 1961, pp. 479t-484t. (Fe61-6)
3. The Resistance of Aluminum Alloys to Corrosion. E. H. Dix, Jr., R. H. Brown and W. W. Binger. Metals Handbook, v. 1, 8th edition, American Society for Metals, 1961, pp. 916-935.

The topics discussed include: contact between dissimilar metals; stress corrosion; atmospheric weathering; resistance to waters; aluminum alloys for the chemical industry. The final section of the paper describes the performance of aluminum with specific chemicals.

1960

1. Evaporated Metal Films As Indicators of Atmospheric Pollution. J. P. Lodge, Jr., and B. R. Havlik. Int. J. Air Pollution, v. 3, No. 4, 1960, pp. 249-252. (Fe60-4)

1959

1. Corrosion of Metals in Synthetic Atmospheres Containing Sulfur Dioxide. B. Sanyal and D. V. Bhadwar. J. Sci. and Ind. Research (India), v. 18A, February 1959, pp. 69-74. (Fe59-3)
2. Deterioration of Materials in Polluted Atmospheres. J. E. Yocum. Corrosion, v. 15, No. 10, October 1959, pp. 541t-545t. (Fe59-5)
3. Mechanism by Which Nonferrous Metals Corrode in the Atmosphere. P. M. Aziz and H. P. Goddard. Corrosion, v. 15, No. 10, 1959, pp. 529t-533t.

Literature dealing with the mechanism by which nonferrous metals corrode in the atmosphere is reviewed, particular emphasis being given to the important series of papers published by W. H. J. Vernon and his co-workers in the period extending from 1923 to the present. The influence of the common atmospheric constituents is discussed and related to the chemical composition and properties of the corrosion product film formed. The influence of these on the atmospheric corrosion rate is also discussed in relation to the nature of the corrosive atmosphere. The atmospheric corrosion of nickel, copper, zinc, aluminum, and magnesium is discussed.

4. Reaction Mechanism for the Atmospheric Corrosion of Metals in Damp and Sulfur Dioxide-Containing Air. K. Barton and E. Beranek. *Werkstoffe u. Korros.*, v. 10, 1959, pp. 377-383. (Fe59-7)

1958

1. Durability Tests of Structural Sandwich. E. W. Kuenzi and L. W. Wood. Symposium on Some Approaches to Durability in Structures, ASTM STP 236, American Society for Testing Materials, 1958, pp 27-34. (Fe58-4)
2. Influence of Dust and the Atmospheric Corrosion of Metals. K. Barton. *Werks. Korros.*, v. 9, Aug-Sept 1958, pp. 547-549 (German). (Fe58-7)
3. Investigation of Effects of Atmospheric Corrosion on Fatigue Life of Aluminum Alloys. H. A. Leybold, H. F. Hardrath, and R. L. Moore. NACA--Tech Note 4331, September 1958, 17 pp.

Corrosion fatigue tests were conducted outdoors at Langley Aeronautical Laboratory on 2024-T3 and 7075-T6 specimens in bare and clad forms. Cyclic loads were applied to 25 specimens 4,000 times in 10 minute periods each working day. For comparison, 24 specimens of each material were tested indoors. Fatigue lifetimes of all materials tested, except 2024 T3 clad, were significantly reduced by atmospheric corrosion.

1957

1. The Corrosion of Aluminum for Building Purposes and Its Prevention. F. Podbreznik. *Zastita Materijala*, v. 5, 1957, pp. 389-394.

The corrosive damages of N_4Cl , asphalt, concrete, fume gases, rubber, lime, $NaHCO_3$, Na_2CO_3 , varnishes, water, wax, wastes, and sea water were determined on aluminum and aluminum alloys. Prevention and cleaning methods are discussed.

2. The Effects of Air Pollution on Buildings and Metalwork. R. J. Schaffer. *Air Pollution*, edited by M. W. Thring Ed. Butterworth Scientific, London, 1957, pp. 58-71. (Fe57-5)

1956

1. Corrosion Studies. X. The Mechanism of the Atmospheric Corrosion of Metals in Moist Atmospheres Contaminated With Sulfur Dioxide. K. Barton and E. Beranek. *Chem. Listy*, v. 50, 1956, pp. 1388-1398. (Fe56-6)

2. Effect of 20-Year Marine Atmosphere Exposure on Some Aluminum Alloys. F. M. Reinhart and G. A. Ellinger. Atmospheric Corrosion of Non-Ferrous Metals, ASTM STP 175, American Society for Testing and Materials, 1956, p. 47.

In 1932, specimens of all commercially available structural aluminum alloys, as well as some experimental alloys, were exposed for long-time weather exposure tests at Coco Solo, Canal Zone, Norfolk, Virginia, and Washington, D.C. The order of merit with regard to corrosion resistance of these alloys was the same for all localities, although the urban atmosphere at Washington was considerably less corrosive than either of the marine atmospheres. Examination after approximately 20 years of exposure revealed that all of the non-heat-treatable alloys containing less than 4 percent of magnesium and one containing about 1 percent of manganese were very resistant to corrosion of the non-heat-treatable alloys, the clad varieties and one alloyed with about 2 percent of cadmium were quite corrosion resistant, while those containing copper, silicon, and manganese were the least resistant. Aluminum-copper alloys were very susceptible to intergranular corrosion and rapid disintegration when improperly quenched or artificially aged unless they were adequately protected. Anodically formed surface films increased the corrosion resistance of the alloys more than did the film formed by immersion in chemical solutions. The most protective paints were those pigmented with zinc chromate and, to a lesser extent, those with aluminum powder. Almost complete protection was afforded by anodically-formed surface films coated with paints pigmented with zinc chromate or aluminum powder or both.

3. Galvanic-couple Corrosion Studies by Means of the Threaded Bolt and Wire Test. K. G. Compton and A. Mendizza. Atmospheric Corrosion of Nonferrous Metals, ASTM STP 175, American Society for Testing and Materials, 1956, pp. 116-125. (Fe56-7)
4. Report of Subcommittee on Atmospheric Corrosion. H. R. Copson. Atmospheric Corrosion of Non-Ferrous Metals, ASTM STP 175, American Society for Testing and Materials, 1956, pp. 3-19.*

The 20-yr. results on corrosion rate, change in tensile strength, and ductility on 24 nonferrous metals and alloys which were exposed to the atmosphere at 7 locations are tabulated in this report. This test is now concluded. No attempt has been made to analyze the data or compare the materials.

5. Resistance of Aluminized Steel to Atmospheric Corrosion. J. C. Merritt and W. E. McFee. Iron Age, v. 178, No. 26, 1956, pp. 60-61.

Aluminum-coated sheet steel is well suited to resist atmospheric corrosion. It stands up well in industrial atmosphere and has good fabricating properties. The coating life of this material is at least 3 times that of commercial-weight zinc coatings in normal or mild industrial atmospheres. Samples have withstood an exposure test now more than 17 years, while zinc coatings on the same exposure test had failed in 12

years. Underwater exposure characteristics are poor. Aluminized steel has a low coefficient of expansion and still has half its normal strength at 900° F. Thickness for thickness, a cost saving of 29 to 45 percent can be expected when aluminized steel is used instead of aluminum. The initial cost is higher than for galvanized steel, but is less than galvanized steel plus one field coat of paint. Painting aluminized steel is unnecessary.

6. Resistance of Aluminum-Base Alloys to 20-Year Atmospheric Exposure. C. J. Walton and W. King. Atmospheric Corrosion of Non-Ferrous Metals, ASTM STP 175, American Society for Testing and Materials, 1956, p. 21

This paper comprises a discussion of the 20-year atmospheric weathering data obtained on wrought aluminum-base alloys included in an investigation on non-ferrous metals sponsored by Committee B-3 of the American Society for Testing Materials. The pertinent data obtained after exposure periods of 1, 3, 6, 10 and 20 years have been tabulated and also arranged graphically to illustrate characteristics of specific interest, such as (1) effect of natural aging on the tensile strength of specimens stored indoors for 20 years; (2) rating of the corrosivity of the seven atmospheric conditions employed; and (3) the rate of weathering of the five aluminum alloys. These important data have been further enhanced by correlating them with equally long-time data obtained by the Aluminum Research Laboratories on similar alloys in other atmospheric environments, and on newer aluminum alloys which now complement or supersede the alloys which had been in the ASTM investigation.

1955

1. Atmospheric Galvanic Couple Corrosion. K. G. Compton, A. Mendizza, and W. W. Bradley. Corrosion, v. 11, No. 9, 1955, pp. 35-44. (Fe55-1)
2. Metal Coatings on Steel in Contact With Aluminum Alloys. Some Comparative Corrosion Tests. S. C. Britton and R. W. de Vere Stacpoole. Metallurgia, v. 52, 1955, pp. 64-70. (Fe55-4)
3. The Corrosion Behavior of Aluminum. H. P. Godard. Corrosion, v. 11, No. 12, 1955, pp. 542-552.

The practical corrosion behavior of aluminum is reviewed for the non-specialist. Included is a discussion of the following topics: the relative nature of corrosion resistance, resistance criteria, factors influencing corrosion rates, common corrosion problems, how to choose a alloy, and galvanic, deposition, crevice and pitting corrosion. Specific information is given on corrosion in six major environments. Other topics considered include corrosion of brazed and welded joints, atmospheric performance of anodized aluminum and preventive measures.

1953

1. Corrosion Resistance of Aluminum and Its Alloys in Industrial Atmosphere
G. Luft and A. Perrone. Alluminio, v. 22, 1953, pp. 256-269.

Aluminum and its alloys, and unprotected and surface-protected ferrous materials were exposed to industrial atmospheres. In the vicinity of the S. Giuseppe di Cairo plant of Montecatini S.A. the atmosphere is more corrosive (because of NO, NO₂, SO₂, CO₂, Ca(NO₃)₂, and sometimes SO₃) than that of Larderello near the fumaroles of boric acid (containing H₃BO₃, NH₃, H₂S, and CO₂). Twelve months' exposure in the first location caused considerable corrosion whereas no corrosion occurred in the second location after 24 months. Aluminum alloys with proper surface treatment are more resistant than are ferrous materials to corrosion in industrial atmospheres.

2. Resistance of Aluminum Alloys to Weathering. C. J. Walton, D. O. Sprowls, and J. A. Nock, Jr. Corrosion, v 9, No. 10, October 1953, pp. 345-358.

Extensive data were selected from tests of thousands of specimens of aluminum alloys, exposed in natural atmosphere for periods as long as 20 years. The effects of weathering were evaluated by measurement of change in strength and depth of attack. The rate of attack was found to decrease to very low values after initial exposure period.

3. Resistance of Aluminum to Chemically Contaminated Atmospheres.
W. W. Binger, R. H. Wagner, and R. H. Brown. Corrosion, v. 4, No. 12 December 1953, pp. 440-447.

Tests at Research Laboratories of Aluminum Co. of America reported effect of chemical dusts on aluminum surface; practical examples of resistance to chemical atmospheres of aluminum roofing and siding; corrosion resistance of aluminum tank roofs. Good results were obtained in the use of aluminum for heat exchangers, piping and tubing.

1952

1. Aluminum. R. L. Horst. Chem. Eng., v. 59, No. 5, May 1952, pp. 300-316.

This paper summarized information on the corrosion resistance of aluminum and its alloys to over 100 common corrosives with data on applications, composition, etc; on types of aluminum equipment used in process industries; and on typical mechanical properties of aluminum alloys.

2. Some Further Observations on the Painting of Aluminum Alloys.
W. A. Edwards. Light Metals, v. 15, No. 167, 1952, pp. 61-63. (Fe52-5)

1951

1. Corrosion of Copper, Aluminum, and Magnesium and Their Alloys. M. Orman and E. Zalesinski. Hutnik, v. 18, 1951, pp. 96-101 (Polish).

A description of different types of corrosion of copper and copper alloys is given. The most frequent types of corrosion are characterized as uniform, local, and strain corrosion. Such factors as the influence of chemical composition and protective coatings are discussed. A review of different aluminum, magnesium alloys is given. The properties of these all tabulated and the corrosion of the other light alloys is discussed.

1950

1. Atmospheric Corrosion of Metallic Materials in Closed Spaces. G. Schikorr. Feinmech. u. Prazis, v. 54, 1950, pp. 3-8.

The effect of various gases in the atmosphere on the corrosion of Al, Pb, Cu, Cr, and Ag is reported.

1949

1. The Effect of Atmospheric Exposures on the Stress Corrosion of Aluminum Alloys. G. Schikorr and G. Wassermann. Z. Metallkunde, v. 40, 1949, pp. 201-205.

Results of 6-year exposure tests of bent and riveted sheets of aluminum-magnesium, aluminum-copper-magnesium, and aluminum-zinc-magnesium alloys in rural, urban, industrial, and marine atmospheres at 17 German locations are summarized in comparison with laboratory tests in 3 percent NaCl solutions at 70°.

1929

1. Atmospheric Corrosion of Metals--3rd Report to the Atmospheric Corrosion Research Committee. J. C. Hudson. Trans. Faraday Soc., v. 25, 1929 pp. 177-252.

Of 16 non-ferrous metals and alloys, most were but slightly subject to atmospheric corrosion. Changes in appearance might influence the use of one or the other if used for decorative purposes. No definite conclusions are presented regarding the rate of corrosion versus time. However, it is believed that there is a direct proportionality between the two. Films of corrosion products may limit further corrosion, depending upon the solubility and chemical composition of the resulting film. For example, arsenical copper is more resistant than high-conductivity copper. Samples fully exposed to the atmosphere show higher rates than those under Stevenson screens. The changes in tensile strength and in electrical

resistance agree closely except for brass, indicating the absence of pitting or intercrystallization corrosion. There is considerable difference between weight loss, the weight increment and the resistance tests. The discrepancies are attributed to wind shelter, to penetration of the metal at crystallization boundaries in weight-loss tests and to local action due to H_2O droplets. Dezincification of brass causes appreciable losses in strength (more for 60/40 brass than for 70/30 brass). The indices of corrodibility outdoors for rural, suburban urban, marine and industrial atmospheres are, respectively, 1.0, 1.6, 2.8, 2.1, and 2.3 with 1, 2.1, 5.8, 2.2, and 2.8 when under Stevenson screens. The corrosion rates in continuous tests show a decrease with time over the periods investigated. Copper, Cd-Cu, As-Cu, Sn-bronze and Al-bronze gave the lowest increments in weight, probably due to the formation of insoluble corrosion products. Evidence is given to show that the existence of critical humidities for the various metals all being below saturation except for aluminum and copper. Nickel is liable to attack without much loss in tensile strength in atmospheres high in sulfur compounds. Resistance methods consistently give higher results than weight-loss tests, because weight-loss measurements are necessarily minimum values.

2. The Relative Corrodibilities of Ferrous and Non-Ferrous Metals and Alloys.
Part II--The Results of Seven Years' Exposure to Air at Birmingham.
J. N. Friend. J. Inst. Metals, v. 42, 1929, pp. 149-155. (Fe29-2)

COPPER ALLOYS

1982

1. A Probe for Monitoring Corrosion In Marine Environments. V. S. Agarwala. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 183-192. (Fe82-1)
2. Acid Rain: Impacts on the Natural and Human Environment. Hans C. Martin. Materials Performance, v. 21, No. 1, 1982, pp. 36-39. (Fe82-3)
3. Atmospheric Active Pollutant Indicator. S. P. Carbone and E. Corl. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 179-182.

Atmospheric contamination detection has been demonstrated with an integrating pollutant sensor. A thin layer of polyethylene glycol 400 placed between adjacent d-c biased copper electrodes was subjected to two environments containing differing levels of sulfur dioxide, hydrogen sulfide, nitrogen dioxide, and chlorine at 25°C and 70% RH. Sensors were also placed in two additional rooms, ambient and 25°C/70% RH environments. Failure rates, as measured by the electrical "shorting" time from the "bridged" metal growth, significantly varied with the pollutant concentration. Elemental microprobe analysis of metal dendritic growth between conductors revealed the presence of sulfur and chlorine. These elements are typically present in atmospheric gases.

4. Atmospheric Corrosion of Copper Alloys Exposed for 15 to 20 years. L. P. Costas. Atmospheric Corrosion of Metals, edited by S. W. Dean, Jr., and E. C. Rhea, American Society for Testing and Materials, ASTM STP, 1982, pp. 106-115.

Copper alloys were exposed for 15 to 20 years at two marine, one industrial, and one rural location. Based on average corrosion rates for 13 alloys, the industrial corrosion rate was 1.4 $\mu\text{m}/\text{year}$ whereas the rate for the other sites was approximately 0.7 $\mu\text{m}/\text{year}$. As expected, alloying agents affected the corrosion rates by a factor of 2 to 3.

General attack was the predominant form of corrosion. Dezincification was positively identified in C260 alloy and intergranular attack was noted in C642. Pitting was not a factor for any alloy.

5. Atmospheric Corrosion of Copper and its Alloys, E. Mattsson and R. Holm. Atmospheric Corrosion, edited by W.H. Ailor, Wiley, New York, N.Y., 1982, pp. 365-382.

A thin invisible oxide coating is formed in dry atmospheres at ambient temperature. Stationary water or hygroscopic impurities on the surface may cause staining. A darkish oxide coating is formed outdoors,

and later on, under favorable conditions, a green patina of basic copper salts. General corrosion (0.5 to 2 $\mu\text{m}/\text{y}$) is the dominating corrosion type. Brasses, especially ($\alpha + \beta$)-brasses, may also suffer dezincification. Brass structures under mechanical tension sometimes fail due to stress corrosion cracking.

6. Atmospheric Corrosion Tests of Copper and Copper Alloys in Sweden - 16 Year Results. R. Holm and E. Mattsson. Atmospheric Corrosion of Metals, edited by S. W. Dean, Jr., and E. C. Rhea, American Society for Testing and Materials, ASTM STP 767, 1982, pp. 85-105.

In 1958, exposure tests were started in rural, marine, and urban atmospheres in Sweden, covering 36 copper alloys in sheet or rod form. Test results after two and seven years' exposure have been reported earlier. This is the concluding report of the tests as completed after 16 years' exposure.

Greenish coatings had developed on most of the materials after six to seven years at the urban and marine sites. At the rural site, however, no distinct green coating had developed on any material after 16 years, only different shades of black or brown. The amount of patina retained increased substantially from 7 to 16 years of exposure. The patina was found to be more protective in the marine and rural atmospheres than in the urban one. The patina was also examined by X-ray analysis and scanning electron microscopy-EDX.

The average penetration (determined gravimetrically during 16 years of exposure had stabilized at the following levels:

- 0.3 to 0.5 $\mu\text{m}/\text{year}$ in rural atmosphere
- 0.5 to 0.9 $\mu\text{m}/\text{year}$ in marine atmosphere
- 0.9 to 1.3 $\mu\text{m}/\text{year}$ in urban atmosphere

The dezincification rate of brass had decreased somewhat during the period from 7 to 16 years. It was highest for brasses with an ($\alpha + \beta$)-phase structure. The maximum dezincification depth measured metallographically after 16 years was 90 to 215 μm . The loss in ultimate tensile strength was 5 to 15 percent and the reduction in elongation ranged up to 30 percent.

7. Atmospheric Corrosion Testing in Australasia. J. F. Moresby, F. M. Reeves and D. J. Spedding. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 745-754. (Fe82-15)
8. Atmospheric Corrosion Testing in Brazil. A. C. Dutra and R. Vianna. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 755-774. (Fe82-16)
9. Atmospheric Corrosion Testing in Finland. T. Hakkarainen and S. Ylasaari. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 787-796. (Fe82-17)

10. Atmospheric Corrosion Testing In the Federal Republic of Germany. G. Oelsner. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 797-806. (Fe82-18)
11. Atmospheric Corrosion Testing in Southern Africa. B. G. Callaghan. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 893-912. (Fe82-21)
12. Atmospheric Corrosion Testing in Spain. S. Feliu and M. Morcillo. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 913-922. (Fe82-22)
13. Atmospheric Corrosion Tests in the USSR. Y. N. Mikhailovskii and P.V. Strekalov. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 923-942. (Fe82-23)
14. Atmospheric Weather Factors in Corrosion Testing. H. Guttman. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 51-68. (Fe82-25)
15. Colloid and Surface Phenomena in the Corrosion of Metals. E. Matijevic. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 123-138. (Fe82-28)
16. Economic Assessment of Pollution Related Corrosion Damage. F. H. Haynie. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 3-18. (Fe82-33)
17. Electrotopography - A New Tool for Corrosion Research. M. Ensanian. Extended Abstracts, International Symposium on Atmospheric Corrosion (October 5-10, 1980, Hollywood, Florida), Electrochemical Society, v. 80-2, 1980, pp. 480-482. (Fe82-36)
18. Environment, Microenvironment, and the Durability of Building Materials. P. J. Sereda and H. E. Ashton. J. Durability of Building Materials, v. 1, No. 1, 1982, pp. 49-66. (Fe82-37)
19. Evaluation of the Effects of Microclimate Differences on Corrosion. F. H. Haynie. Atmospheric Corrosion of Metals, edited by S. W. Dean, Jr., and E. C. Rhea, American Society for Testing and Materials, ASTM STP 767, 1982, pp. 286-308. (Fe82-39)
20. General, Localized, and Stress-Corrosion Resistance of a Series of Copper Alloys in Natural Atmospheres. A. P. Castillo and J. M. Popplewell.

Atmospheric Corrosion of Metals, edited by S. W. Dean, Jr. and E. C. Rhea, American Society for Testing and Materials, ASTM STP 767, 1982, pp. 60-84.

The general, localized, and stress-corrosion performance of a series of copper-base alloys exposed to marine, urban-industrial, and heavy industrial environments is described after 12 years' exposure. The effect of alloying additions, test environment, and test parameters are reported versus corrosion susceptibility.

21. Indoor Atmospheric Corrosion of Copper, Silver, Nickel, Cobalt and Iron. D. W. Rice, R. J. Cappell, P. B. P. Phipps, and P. J. Peterson. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 651-666.

The current understanding of the indoor corrosion of copper, silver, nickel, cobalt, and iron is discussed as a subset of the broad problem of atmospheric corrosion. The quantitative importance of water vapor and certain pollutants is presented followed by a discussion of the magnitude of indoor corrosion, statistical aspects of indoor corrosion, indoor atmospheric parameters, and a comparison to outdoor pollutant and rate data.

22. Passivation of Copper: Role of Some Anions in the Mechanism of Film Formation and Breakdown. F. M. Al-Kharafi and Y. A. El-Tantawy. Corr. Sci., v. 22, No. 1, 1982, pp. 1-12.

The effect of SO_4^{2-} , Cl^- and I^- ions on the anodic currents of the successive passivating processes that take place in alkaline phosphate solutions, on the above has been studied using potentiodynamic, galvanodynamic and open circuit potential measurements. Additions of I^- resulted in the largest current increase followed by Cl^- . Additions of SO_4^{2-} showed an initial anodic current decrease, a trend that was reversed with the progress of cycle number. While the current increase, of Cu(I) oxide, with increasing halide additions, follows closely:

$$\Delta i = \frac{(A[X^-])}{(B + m[X^-])}$$

that of the Cu(II) oxide process obeyed

$$\Delta i = A[X^-]$$

where Δi is the increase in peak current and $[X^-]$ the halide concentration added. A mechanism involving adsorption of the halide ions on the electrode surface and/or exchange with OH^- attached to the soluble metal ion is discussed.

23. Progress in Atmospheric Corrosion Testing. D. Knotkova, K. Barton and M. Cerny. Extended Abstracts, International Symposium on Atmospheric

Corrosion (October 5-10, Hollywood, Florida), Electrochemical Society, v. 80-2, 1980, pp. 526-528. (Fe82-44)

24. Rapid Methods for Determining Atmospheric Corrosivity and Corrosion Resistance. D. P. Doyle and T. E. Wright. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 227-244. (Fe82-45)
25. Reproducibility of Electrochemical Measurements of Atmospheric Corrosion Phenomena. F. Mansfeld, S. Tsai, S. Jeanjaquet, E. Meyer, K. Fertig and C. Ogden. Atmospheric Corrosion of Metals, edited by S. W. Dean, Jr., and E. C. Rhea, American Society for Testing and Materials, ASTM STP 767, 1982, pp. 309-338. (Fe82-46)
26. Stress Corrosion of Metals in the Atmosphere. A. Gallacio. Extended Abstracts, International Symposium on Atmospheric Corrosion (October 5-10, 1980, Hollywood, Florida), Electrochemical Society, v. 80-2, 1980, pp. 581-582. (Fe82-47)
27. The Atmospheric Corrosion of Tin and Tin Alloys. M. E. Warwick and W. B. Hampshire. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 509-528.

The atmospheric corrosion of tin and the formation and nature of oxide films in various environments is discussed. The effect of various gases and organic vapors in the atmosphere and of minor additions of other metals to tin are considered. The atmospheric corrosion of solders and bronzes is reviewed. Tin alloy coatings are of major importance and their resistance to atmospheric corrosion is assessed. The most important tin alloy coatings include tinfoil, tin-lead, tin-copper, tin-zinc, tin-cadmium, tin-nickel, and tin-cobalt.

28. The Interplay of Weather, Climate and the Durability of Materials. P. W. Brown and L. W. Masters. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 31-50. (Fe82-48)
29. The Sulfiding of Copper by Trace Amounts of Hydrogen Sulfide. J. P. Franey, T. E. Graedel, and G. W. Kammlott. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 583-592.

The kinetics and morphology of copper sulfide film growth have been explored over a wide range of H_2S concentrations, relative humidities, and temperatures, with the aim of specifying in some detail the mechanisms of copper sulfidation. The calibrated growth curves confirm and augment previous suggestions of nonlinear growth of the tarnish films, particularly in the early stages of formation. SEM analyses of these films indicates that the spatial inhomogeneity of the film growth is involved in this nonlinear behavior.

30. Theoretical and Engineering Principles of Atmospheric Corrosion of Metals. Y. N. Mikhailovskii. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 85-106. (Fe82-52)

1981

1. Acid Rain: Impacts on the Natural and Human Environment. H. C. Martin. Paper No. 114, Corrosion/ 81, Toronto, Canada, National Association of Corrosion Engineers, Houston, TX, April 6-10, 1981, 7 pp. (Fe81-1)
2. An American Tragedy. R. H. Boyle. Sports Illustrated, v. 55, No. 13, September 21, 1981, pp. 68-82. (Fe81-2)
3. Atmospheric Corrosion of Copper and Silver. D. W. Rice, P. J. Peterson, E. B. Rigby, P. B. P. Phipps, R. J. Cappell, and R. Tremoureux. J. Electrochem. Soc., v. 128, No. 2, 1981, pp. 275-284.

The corrosion rate of copper in laboratory tests is shown to be a sensitive function of relative humidity and sulfur dioxide, hydrogen sulfide, ozone, hydrogen chloride, and chlorine concentrations. Observed indoor corrosion rates obey log normal statistics over the field population of this study. Also, the observed indoor rates correlate reasonably well with the measured reduced sulfur concentrations (H_2S , S_2). The

corrosion rate of silver is shown not to be humidity dependent. Hydrogen sulfide, ozone, chlorine, and hydrogen chloride concentrations substantially influence its corrosion rate. The observed indoor rates obey log normal statistics and correlate well with the reduced sulfur gas concentration. In contrast to copper, where indoor rates are 1 percent of outdoor values, silver often corrodes faster indoors than outdoors. Its sensitivity to sulfur gases and insensitivity to relative humidity is proposed as a plausible explanation for these findings. It is proposed that metallic silver is stable in polluted acidic atmospheric environments and therefore is the dominant surface species while Cu_2O is present on the surface of copper. The thermochemistry and kinetics of these two surfaces will control the stability of silver and copper, respectively, in the presence of pollutants.

4. Carbonyl Sulfide: Potential Agent of Atmospheric Sulfur Corrosion. T. E. Graedel, G. W. Kammlott, and J. P. Franey. Science, v. 212, May 8, 1981, pp. 663-665.

Laboratory exposure experiments demonstrate that carbonyl sulfide in wet air corrodes copper at 22°C at a rate that is approximately linear with total exposure (the product of exposure time and carbonyl sulfide concentration). The corrosion rate is similar to that of hydrogen sulfide, a widely recognized corrodant. The much greater average atmospheric

abundance of carbonyl sulfide compared with that of hydrogen sulfide or sulfur dioxide suggests that carbonyl sulfide may be a major agent of atmospheric sulfur corrosion.

5. Determination of the Corrosivity of Atmospheres with Electrochemical Techniques. F. Mansfeld. Extended Abstracts, Fall Meeting, Electrochemical Society, Denver, Colorado, v. 81-2, October 11-16, 1981, pp. 444-445. (Fe81-7)
6. Evaluation of Electrochemical Techniques for Monitoring of Atmospheric Corrosion Phenomena. F. Mansfeld. Electrochemical Corrosion Testing, ASTM STP 727, edited by F. Mansfeld and U. Bertocci, American Society For Testing and Materials, 1981, pp. 215-237. (Fe81-9)
7. How Menacing is Acid Rain? A. LaBastille. National Geographic, v. 160, No. 5, November 1981, p. 652-681.

Fishless lakes in North America and Scandinavia raise concern about the chemical showers that observe no boundaries and pose many questions. Among the environmental damages attributed to acid rain are stone damage on Canadian Parliament buildings, the Acropolis, Egypt's temples at Karnak, the U.S. Capitol, and corrosion damage to the Statue of Liberty.

8. Practical Experience with an Electrochemical Technique for Atmospheric Corrosion Monitoring. V. Kucera and J. Gullman. Electrochemical Corrosion Testing, ASTM STP 727, edited by F. Mansfeld and U. Bertocci, American Society for Testing and Materials, 1981, pp. 238-255. (Fe81-12)

1980

1. A Model of Atmospheric Corrosion of Metals Allowing for Meteorological and Aerochemical Characteristics. Yu. N. Mikhailovskii, P. V. Strekalov, and V. V. Agafonov. Protection of Metals, v. 16, No. 4, 1980, pp. 308-323. (Fe80-1)
2. A Review of Air Pollutant Damage to Materials. J. E. Yocum and A. R. Stankunas. Draft report to Environmental Criteria and Assessment Office, Office of Research and Development, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, December 1980, 92 pp. (Fe80-2)
3. Background and Principles of Long-Term Performance of Building Materials. S. E. Pihlajavaara. Durability of Building Materials and Components, ASTM STP 691, edited by P. J. Sereda and G. G. Litvan, American Society for Testing and Materials, 1980, pp. 5-16. (Fe80-4)

4. Corrosion and Preservation of Bronze Artifacts. R. Walker. J. Chem., v. 57, No. 4, April 1980, pp. 277-280.

The historical background for compositions of artifacts is given as well as the mechanisms by which they corrode. Protection methods are also discussed.

5. Corrosion of Metal in Wood Products. A. J. Baker. Durability of Building Materials and Components, ASTM STP 691, edited by P. J. Sereda and G. G. Litvan, American Society for Testing and Materials, 1980, pp. 981-993. (Fe80-7)
6. Critical Review of the Available Physico-Chemical Material Damage Functions of Air Pollution. M. Benarie. Report EUR 6643 Commission on the European Communities, 1980, 97 pp. (Fe80-8)
7. Indoor Corrosion of Metals. D. W. Rice, R. J. Cappell, W. Kinsolving, and J. J. Laskowski. J. of Electrochem. Soc., v. 127, No. 4, 1980, pp. 891-901. (Fe80-11)
8. Metals in America's Historic Buildings. M. Gayle, D. W. Look, and J. G. Waite. U.S. Department of the Interior, Heritage Conservation and Recreation Service, Washington, D.C., 1980, 170 pp. (Fe80-14)

1979

1. Atmospheric Corrosion of Metallic Systems. II. Analysis of the Corrosiveness of a Medium at Atmospheric Testing Stations of Comecon Countries Based on the Results of Five-Year Tests on Steel, Zinc, Copper, and Aluminum. K. Barton, D. Knotkova, P. V. Strekalov, V. Kemkhadze, V. Kozhukharov, and A. Szobor. Zashch Met., v. 15, No. 4, 1979, pp. 408-415 (Russian). (Fe79-1)
2. Electrochemical Studies of Atmospheric Corrosion. F. B. Mansfield. NTIS Report AD-A063922, January 1979, 135 pp. (Fe79-6)
3. On the Conservation of the Baptistery Doors in Florence. G. Alessandrini, G. Dassu, P. Pedferri, and G. Re. Studies in Conservation, v. 24, 1979, pp. 108-124.

The causes of deterioration of the gilded bronze doors of the Batistery in Florence have been examined and the mechanism of corrosion discussed. An apparatus for thermal conditioning has been proposed and tested either on the north door of the Baptister, or on samples exposed to the urban atmosphere in Milan and by laboratory tests on an electro-

chemical model. The effectiveness of the proposed apparatus has been verified by weight losses, assessing soluble salts, by visual observations, by local chemical microanalyses, by morphological examinations with a scanning electron microscope equipped with an X-spectrometer and by X-ray diffraction.

4. Statistical Assessment of the Effect of Fluctuations in the Atmospheric Concentration of Sulfur Dioxide on the Corrosion Rate of Metals. Yu N. Mikhailovskii and A. P. San'ko. *Zashch. Met.*, v. 15, No. 4, 1979, pp. 432-437 (Russian). (Fe79-8)
5. Studies on Air Dusts and Cultural Property. II. Examination of Deposits on Copper Plated Roofs with Scanning Microscope and X-ray Microanalyzer. T. Kadokura, Y. Suzuki, and S. Nishiate. *Conservation for Science*, No. 18, 1979, pp. 19-25 (Japanese).

In recent years, the verdigris color of copper plated roofs in Japanese urban areas has changed to a brownish color. The authors investigated the cause of this color change using a scanning electron microscope and X-ray microanalyzer.

The authors compared a verdigris colored copper plate (Sample A) and a brown colored copper plate (Sample B) taken from the roof of the Hyokeikan, a building in the Tokyo National Museum which was built in 1901. Secondary electron images revealed the following features.

Sample A: the verdigris surface of the plate shows innumerable indentations, 5-20 μm in width, clustered closely together.

Sample B: brown tarnish deposits cover the verdigris surface of the copper plate like a thin film. This film easily flakes off together with the underlying layer of copper rust. The results of X-ray microanalyzer tests on the surfaces of Sample A and B are shown.

Cross sectional X-ray microprobe images of the test samples revealed that rust thickness was about 40 μm thick on Sample A and about 110 μm on Sample B. As for the distribution of elements in the rust, Sample B was characterized by high concentrations of iron and phosphorus.

From the above measurements the authors concluded that the cause of the color change was due to the adherence of layers of iron to the verdigris surface. These layers of iron were probably formed when iron particles, produced by the wearing of railroad tracks and motor vehicle engines, combined with wind blown dust containing pigeon dung or organic insecticides and then settled on the verdigris copper plate.

6. The Effect of Atmospheric Corrosion on the Reliability of Electronic Parts. B. Henzlik. *Koroze Ochr. Mater.*, v. 5, 1979, pp. 90-91 (Czech).

The effect of atmospheric corrosion on electronic parts is examined. A system of atmospheric tests is proposed as an alternative to classical methods of corrosion resistance testing.

7. The Effect of Soil Conditions on Long-Term Corrosion of Buried Tin-Bronzes and Copper. R. F. Tylecote. *Journal of Archaeological Science*, v. 6, No. 4, 1979, pp. 345-368.

The principal factor in the corrosion of buried bronze and copper objects is the pH. Acid soils are aggressive while alkaline soils are benign. In spite of its acidity, peat preserves well, probably due to the presence of polyphenols. No involvement of sulfate-reducing bacteria was found.

1978

1. A New Composition of Patina From the Roof of the Wawel Cathedral. E. M. Nosek. ICOM Committee for Conservation, 5th, Zagreb, Nos. 23-26, 1978, 6 pp.

Results are presented of chemical and X-ray diffraction analyses of samples of corrosion products taken from the gilded objects on the surface of the Sigismund chapel cupola and the roof of the Wawel Cathedral in Cracow. This research has established the origin of this corrosion of bronze objects and identified the composition of the corrosion products, as well as determined the influence of the atmospheric pollution on the patina.

2. An Accelerated Atmospheric Corrosion Test (AACT). R. D. Smith. *Atmospheric Factors Affecting the Corrosion of Engineering Metals*, ASTM STP 646, edited by S. K. Coburn, American Society for Testing and Materials, 1978, pp. 160-164.

A laboratory test method for accelerated atmospheric corrosion testing has been developed. Copper alloys were the main subject of testing, and the principal atmospheric simulation was urban-industrial. The test method has been very useful in ranking experimental copper alloys relative to commercial alloys and is believed to be adaptable to other alloy systems and environments. Representative reproducible oxide films can be generated for film study work and kinetics of film formation can be followed easily.

3. ASTM Atmospheric Corrosion Testing: 1906 to 1976. W. J. Ailor. *Atmospheric Factors Affecting the Corrosion of Engineering Metals*, ASTM STP 646, edited by S. K. Coburn, American Society for Testing and Materials, 1978, pp. 129-151. (Fe78-2)
4. Atmospheric Corrosion. M. G. Fontana and N. D. Greene. Chapt. 8 in *Corrosion Engineering*, McGraw-Hill Company, 2nd ed., 1978, pp. 265-268. (Fe78-3)

5. Atmospheric Corrosion of Electroplated Zinc Alloy Die Castings. J. H. Payer and W. H. Safranek. Atmospheric Factors Affecting the Corrosion of Engineering Metals, ASTM STP 646, edited by S. K. Coburn, American Society for Testing and Materials, 1978, pp. 115-128.

The effect of electroplating variables on atmospheric corrosion of copper, nickel, and chromium electroplates on zinc alloy die castings was investigated at mobile and stationary test sites. More than 3,000 electroplated die castings were exposed on Detroit, Michigan, trucks; Youngstown, Ohio, trucks; New York City tugboats; Detroit, Michigan, roof tops; and at Kure Beach, North Carolina, 245-m (800-ft) lot, for periods of up to 10 years. Exposure to mobile test sites provided a valuable supplement to the more conventional stationary test site. The application of microdiscontinuous chromium proved to be the most influential factor for improved corrosion resistance.

6. Atmospheric Corrosion of Laminar Composites Consisting of Copper on Stainless Steel. R. Baboian, G. Haynes, and P. Sexton. Atmospheric Factors Affecting the Corrosion of Engineering Metals, ASTM STP 646, edited by S. K. Coburn, American Society for Testing and Materials, 1978, pp. 185-203. (Fe78-6).
7. Atmospheric Laboratory Bench. Yu. N. Mikhailovskii, V. A. San'ko, N. A. Sokolov, and P. N. Kudnyavtsev. Zashch. Met., v. 14, No. 4, 1978, pp. 515-517 (Russian). (Fe78-7)
8. Corrosion Investigations at Panama Canal Zone. M. A. Pelensky, J. J. Jaworski, and A. Gallaccio. Atmospheric Factors Affecting the Corrosion of Engineering Metals, ASTM STP 646, edited by S. K. Coburn, American Society for Testing and Materials, 1978, pp. 58-73. (Fe78-9)
9. Deteriorative Effect of Sulfur Pollution on Materials. J. O. Nriagu. Chapt. 1 in Sulfur in the Environment, Part II: Ecological Impacts, edited by J. O. Nriagu, Wiley, New York, N.Y., 1978, pp. 1-59. (Fe78-11)
10. Protection of Copper Metals from Atmospheric Corrosion. L. D. Fitzgerald. Atmospheric Factors Affecting the Corrosion of Engineering Metals, ASTM STP 646, edited by S. K. Coburn, American Society for Testing and Materials, 1978, pp. 152-159.

The development of a synthetic patina process for copper metals is described. The chemistry of the process essentially parallels the natural atmospheric corrosion of copper. Various stages of the patination system are illustrated via scanning electron microscopy photographs.

The development of organic resin-based coating systems are described, including passivation systems, solvent selection and resin screening techniques. An accelerated weathering test program for evaluation of clear coatings is detailed. Field evaluation at various test sites are

correlated with coating properties. They illustrate the effect of atmospheric contaminants, sea spray contamination, and high ultraviolet intensity exposure effects as they pertain to coating life.

Field tests of the inorganic patina and of both an organic lacquer and a shop-applied film coating system are described indicating the potential durability of the system.

11. Recent Developments in the Conservation of Outdoor Bronze Monuments. P. Gaspar, L. Gulbransen, and P. D. Weil. 5th ICOM Committee for Conservation, Zagreb, 1978, 78/23/12/1-7.

Cleaning procedures, by glass bead peening, of two bronze statues in St. Louis are described. The amount of loss by corrosion is noted as well as the safety of the cleaning procedure. Mention is made of both comparative conditions of other bronze statues and corrosion tests which the authors are undertaking on two bronze alloys.

12. The Bioaggression on St. Mark's Horses. A. Paleni, E. E. Staffeldt, and S. B. Curri. Poligrafico Artioli Editore, Modena, Italy, 1978, 8 pp.

Professor Staffeldt, professor of biology at New Mexico State University, suggests an interpretation of corrosion phenomena on the surface of the St. Mark's Horses. Alunno-Rossetti and Marabelli (Studies in Conservation, v. 21, pp. 161-170 (1976)) considered the same problem with quite different conclusions. Staffeldt feels the oxalic acid on the surface of the horses is a product of microbial life. Rossetti considers this to be a hypothesis, and feels that the acid is caused by oxidation of hydrocarbons in smog. The debate is reviewed in detail.

13. The Corrosion and Protection of Metals in the Building and Construction Industries. B. G. Callaghan. J. Oil Color Chemists Assoc., v. 61, No. 11, November 1978, pp. 411-418. (Fe78-17)

1977

1. Corrosion Products Formed on Copper Exposed to Humid Sulfur Dioxide-Containing Atmospheres. R. Ericsson and T. Sydberger. Werkst. Korros., v. 28, No. 11, 1977, pp. 755-757.

Exposure of 99.9 pct. Cu specimens to humid atmospheres containing 10-100 ppm SO_2 resulted in the formation of patina consisting of $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ and $\text{Cu(I)}_2\text{Cu(II)(SO}_3)_2 \cdot 2\text{H}_2\text{O}$. When the SO_2 supply was interrupted, Cu_2O was formed. The sulfate and the sulfite were converted into unidentified compounds. On continued exposure, the compound was converted into $\text{CuSO}_4 \cdot 2\text{Cu(OH)}_2$. During prolonged exposures, $\text{CuSO}_4 \cdot 3\text{Cu(OH)}_2$ was also formed. Intermediate wetting of specimens preexposed to SO_2 containing atmospheres resulted in formation of $\text{CuSO}_4 \cdot 3\text{Cu(OH)}_2 \cdot 2\text{H}_2\text{O}$ in addition to other corrosion products.

2. Estimation of Pollutants Concentration in Atmosphere by Measuring Corrosion Rates of Several Metals. II. Correlation Between Reflectances of Exposed Metals and Deterioration of Exposed Rubber. G. Takao, and M. Masakasu. Taiki Osen Kenkyu, v. 11, No. 6, 1977, pp. 452-455 (Japanese).

Rubber deterioration depends on the atmospheric corrosion of metals or on atmospheric pollution by the relation between corrosion of Ag, Cu, and Zn and their reflectances of red or blue lights was determined. The ratio of the deterioration of exposed rubber to that of unexposed rubber was calculated for samples taken at 5 different zones. The relation between this ratio and the reflectance of metals was obtained. Oxidants or peroxides are atmospheric pollutants on metals.

3. Galvanic Corrosion In the Atmosphere. V. Kucera. Rapp. - Korrosionsinst., No. 16, 1977, 43 pp. (Swedish). (Fe77-9)
4. Radiochemical Study of the Use of Benzotriazole for the Protection of Copper Exposed to the Attack of Sulfur Dioxide. R. Ferrari, M. Marabelli, M. Serra, and G. Starace. British Corrosion Journal, v. 12, No. 2, 1977, pp. 118-121.

Radiochemical studies indicate that the quantity of sulfur dioxide adsorbed by the treated samples is always less than bare copper. This may infer that BTA provides some protection. Almost total oxidation of sulfur dioxide occurs, however, for the treated samples under all experimental conditions employed.

5. Study of Atmospheric Corrosion Inhibitors on Metal Surfaces by X-Ray Electron Spectroscopy. A. M. Novitskii, Ya. V. Salyn, and V. I. Nefedov. Zashch. Met., v. 13, No. 2, 1977, pp. 209-212 (Russian). (Fe77-13)

1976

1. Analyses of the Patinas of a Gilded Horse of St. Mark's Basilica in Venice: Corrosion Mechanisms and Conservation Problems. V. Alunno-Rossetti and M. Marabelli. Studies in Conservation, v. 21, 1976, pp. 161-170.

An extensive sampling has been carried out of corrosion products and encrustations on the surface of a gilded horse of St. Mark's Basilica in Venice. Physical and chemical analyses have allowed us to identify typical compounds, propose mechanisms of deterioration, and define some conservation problems of the statues in outdoor exposure.

2. Conservation of Outdoor Bronze Sculpture. P. D. Weil. National Sculpture Review, v. 25, No. 5, Fall 1976, pp. 26-30.

The Center for Archaeometry was established in 1975, at the University of Washington in St. Louis to determine the causes and mechanics of deterioration of outdoor bronze sculpture, and to investigate and carry out methods for their restoration and preservation.

The process of corrosion is recounted to show that the green patina is neither attractive nor protective, but is disfiguring and destructive. Further Ms. Weil indicates that although the fairly recently-developed artificial patinas are sometimes applied to hide casting flaws, they are also used to imitate the corroded surfaces, mistakenly believed to be original, on ancient bronzes.

Treatment methods tested by the Center and used successfully on many outdoor bronzes in St. Louis, include the removal of the corrosion product by cleaning with glass beads, and the application of a protective coating of Incralac, an acrylic resin with benzotriazole, a corrosion inhibitor, in it.

3. Effects of Power Plant Emissions on Materials. J. E. Yocom and N. Grappone. Research Corporation of New England, Wethersfield, Connecticut, NTIS Report PB-257539, July 1976, 85 pp. (Fe76-6)
4. Electrochemical Monitoring of Atmospheric Corrosion Phenomena. F. Mansfield and J. V. Kenkel. Corrosion Science, v. 16, No. 3, 1976, pp. 111-122. (Fe76-9)
5. How Environmental Pollutants Diminish Contact Reliability. C. A. Russell. Insulation/Circuits, v. 22, No. 10, 1976, pp. 43-46.

Environmental damage to electrical contacts by airborne particles and aerosols is discussed. Particulate deposition, tarnishing, organic or carbon film formation, and accelerated contact were among the damages observed resulting in high contact resistance or noise.

6. Problems of Conservation of the Doors of the Battistero in Florence. G. Dassu, G. Piazzesi, and G. Alessandrini. Conservazione dei Monumenti, 1976, pp. 155-165 (Italian).

The deterioration causes of the three doors of Battistero are examined and a brief history of the doors is given together with a description of the mechanism of corrosion. An experimental equipment for thermal conditioning installed at the back of the north door is described and the results obtained are reported.

7. Protecting Electronics From Atmospheric Corrosion. D. V. Couden. Materials Engineering, May 1976, pp. 22-25.

The electronics industry losses million of dollars each year to atmospheric corrosion. Even if urban air pollution were decreased 50 pct. by 1983, the effect on corrosion failures would be virtually nil. However, there are several alternative ways by which these lost dollars can be saved.

8. Protection Against Atmospheric Corrosion. K. Barton. Translated by J. R. Duncan. J. Wiley, New York, N.Y., 1976, 194 pp. (Fe76-14)
9. Use of the Method of Polarization Resistance for Studying the Atmospheric Corrosion of Metals. V. A. Kuznetsov, S. G. Polyakov, Yu. S. Gerasimenko, and Yu. G. Kotlov. Zashch. Met., v. 12, No. 6, 1976, pp. 667-670 (Russian). (Fe76-19)

1975

1. Electrochemical Method for Atmospheric Corrosion Testing of Metals. V. Kucera and E. Mattsoon. Proc. 7th Scand. Corrosion Congress, 1975, pp. 202-217. (Fe75-10)
2. Environmental Exposure System for Studying Air Pollution Damage to Materials. J. W. Spence, F. O. Stump, F. H. Hayne and J. B. Uphank. NTIS Report PB-240615, 1975, 46 pp. (Fe75-11)
3. Studies on Metal Corrosion Caused by Air Pollutants. II. Analysis of Copper Plate Surface in Atmospheres such as SO₂ and NO_x by Auger Electron Spectroscopy. S. Suzuki, K. Matsumoto, and H. Sato. Chiba Daigaku Kenkyu Hokoku, No. 2, 1975, pp. 59-68 (Japanese).

A copper plate (1 by 1 by 0.1 cm) was treated with concentrated nitric acid and the surfaces were thoroughly cleaned with distilled water. The plate was placed in a 100 ml tube reactor which was connected to a vacuum line. After drying at 5×10^{-3} torr for 0.1 to 1.0 hours, water was injected through a silicon rubber stopper. The water was evaporated and nitrogen dioxide or sulfur dioxide was introduced with a syringe. After exposure, the pressure was reduced to 10^{-7} torr and the Auger spectrum was recorded. Argon gas was then added to create a pressure of 10^{-6} torr and the Auger spectrum was again recorded. Elements including oxygen, sulfur, nitrogen, silver, chlorine, and carbon were detected on the copper surface. Corrosion was detected before argon was introduced. Nitrogen and S disappeared after argon etching occurred.

4. Sulfur Dioxide and Material Damage. D. G. Gillette. J. Air Pollution Control Assn., v. 25, no. 12, December 1975, pp. 1238-1243. (Fe75-17)
5. The Approximate Two-Year Lifetime of Inralac on Outdoor Bronze Sculpture. P. D. Weil. ICOM Committee for Conservation, 4th Triennial Meeting, Venice, October 1975, Int. Council of Museums, Paris, 1975, No. 22-2, 4 pp.

This paper reports empirical observations of five outdoor bronzes that received a coating of Inralac in April and May of 1972. Inralac is an acrylic solvent-type coating plus corrosion-inhibitor formulated by the

International Copper Research Association primarily for industrial and architectural application in the maintenance of unpatinated bronze and copper. The need for a durable protective coating on outdoor bronze sculpture has been amply demonstrated. Incralac provided good protection to the five bronzes over a two-year period exposed to an outdoor urban environment. On bronzes that received an additional coating of microcrystalline wax, periodically reapplied, the Incralac coating lasted for almost three years. The coating lasted least well on a patina that showed the most degradation prior to application. The coating retarded but did not stop the condition of exudation of core material on two of the bronzes. Efforts presently being made in adapting the use of Incralac to the special case of fountain sculpture will be discussed, including: application, removal, and combination with additional films for gloss adjustment, increased durability, and resistance to moisture in the special case of fountain sculpture.

6. The Outdoor Corrosion Performance of Plated ABS Plastics. V. E. Carter. Trans. Inst. Metal Finishing, Spring/Conf., v. 53, No. 1, 1975, pp. 61-64.**

ABS plastics plated with Cu-Ni-Cr coatings give satisfactory performance in mobile outdoor service for up to 3 1/2 years. Little difference is experienced in performance with duplex Ni instead of bright Ni. Superior performance is achieved with microporous Cr rather than regular Cr.

1974

1. Air Pollution Effects on Catastrophic Failure of Metals. J. Gerhard and F. H. Haynie. Environmental Protection Agency, EPA-650/3-74-009, November 1974, 33 pp. (Fe74-2)
2. Corrosion Aggressivity of Model Regions of Czechslovakia. D. Knotkova-Cermakova, B. Bosek, and J. Vlckova. Corrosion in Natural Environments, ASTM STP 558, American Society for Testing and Materials, 1974, pp. 52-74. (Fe74-8)
3. Corrosion of Metals in the Atmosphere. W. K. Boyd and F. W. Fink. MCIC-74-23, Battelle-Columbus Labs., Metals and Ceramic Information Center, Columbus, Ohio, August 1974, 77 pp. (Fe74-9)
4. Electrochemical Technique for Determination of the Instantaneous Rate of Atmospheric Corrosion. V. Kucera and E. Mattsson. Corrosion in Natural Environments, ASTM STP 558, American Society for Testing and Materials, 1974, pp. 239-260. (Fe74-15)

5. Pollution Damage to Works of Art. J. Riederer. Chapt. in New Concepts in Air Pollution Research, Birkhauser Verlag, Basel und Stuttgart, 1974, pp. 73-85.

The influence of air pollution on works of art and the research in Germany on this subject are described. The influence of air pollution on stone is not considered to be of practical importance, since natural weathering is more pronounced. Bronzes are threatened by air pollution, particularly if they are cast with alloys rich in lead. Modern bronzes which contain tin, zinc, and small amounts of lead are resistant to air pollution. There is little scientific research in Germany concerning glass windows; Newton's opinion that the decay of painted windows is a natural hydration process is accepted. Wall paintings suffer from layers of soot which are deposited on their surface. Paintings in the interior of museums should be covered with glass to protect them from dirt.

6. Problems of Preservation of Outdoor Bronze Sculpture: Examination and Treatment of The Meeting of the Waters in St. Louis, Missouri. P. D. Weil. Bull. AIC, v. 14, No. 2, 1974, pp. 84-92.

The study presents the unusual preservation problems of the nineteen bronzes comprising the large fountain entitled The Meeting of the Waters by Carl Milles in St. Louis, Missouri. Samples of incrustation were studied by microchemical analysis, in cross-sections, by X-ray diffraction analysis, and with a stereoscan electron microscope with electron microprobe. Removal of the incrustations is described.

The remains of the original matte, blue-green patina were thin, and in many areas had been worn away. The most surprising characteristic of the revealed patina was that it became transparent when wet.

Looking toward the future maintenance of the sculpture, there seemed to be two choices: (1) treatment of the water including deionization and heating so that the fountain could be running the year round, or (2) providing a coating which periodically could be removed, together with any accretions which may have accumulated, and then renewed. "Incralac" was chosen as the most suitable coating material for the bronzes. The treatment was about half way completed at the time of writing.

7. Rapid Electrochemical Procedure to Measure the Atmospheric Corrosion Resistance. E. Erdos. Galvano-Organo, No. 443, April 1974, pp. 382-385 (French).

A new testing method has been elaborated to determine in some hours the resistance of metals and alloys and inorganic non-metals against atmospheric corrosion. Tests were done with certain metals and alloys as Zn, Cd, Sn, and Cu/Ni/Cr. An advantageous side effect of this method is that, during the process, a "copy-contact" formed which reflects faithfully the picture of the deterioration. Above all this, in the case of multilayers, the method can determine exactly the depth of penetration of corrosion. Since oxygen is the most corrosive agent, it was chosen to start with. To accelerate the corrosion process, atomic oxygen was used instead of molecular oxygen.

8. Seven-Year Exposure at Point Reyes, California. W. H. Ailor. Corrosion in Natural Environments, ASTM STP 558, American Society for Testing and Materials, 1974, pp. 75-81. (A174-6)
9. Short-Term Atmospheric Corrosion of Various Copper-Base Alloys: Two- and Four-Year Results. R. S. Herman, and A. P. Castillo. Corrosion in Natural Environments, ASTM STP 558, American Society for Testing and Materials, 1974, pp. 82-96.

Corrosion data pertaining to a variety of copper-base alloys after two- and four-year exposure to natural environments at New Haven, Connecticut, Brooklyn, New York, and Daytona Beach, Florida are presented. High zinc alloys, cartridge brass alloy B36(260) and nickel silver alloy B122(770) experienced substantial decreases in mechanical properties due to "plug type" dezincification and pitting. In addition, the rate of attack on high zinc containing alloys was environment specific. Alloy (619), a copper-aluminum-iron alloy, displayed substantial increases in mechanical properties with time. This is attributed to a long-term low-temperature order-disorder mechanism. The degree of patination was alloy, time, and environment specific. To avoid ambiguity, it is suggested that instantaneous corrosion rate rather than changes in absolute weight loss be used as the criterion for duration of atmospheric testing of copper-base alloys.

10. The Economic Damages of Air Pollution. T. E. Waddell. NTIS Report PB-235701, 1974, 156 pp. (Fe74-21)
11. The Mode of Initial Reaction of SO₂ at a Metal Surface. J. R. Duncann and D. J. Spedding. Corrosion Science, v. 14, No. 4, 1974, pp. 241-249. (Fe74-23)
12. The Use of Weather and Climatological Data in Evaluating the Durability of Building Components and Materials. L. W. Masters and W. C. Wolfe. NTIS Report COM-74-50841/7 August 1974, 102 pp. (Fe74-25)
13. Weather Factors Affecting Corrosion of Metals. P. J. Sereda. Corrosion in Natural Environments, ASTM STP 558, American Society for Testing and Materials, 1974, pp. 7-22. (Fe74-27)

1973

1. Corrosion Caused by Perspiration. G. A. Tret'yakova and V. P. Barannik. Zashch. Metal., v. 9, No. 6, 1973, pp. 715-717 (Russian). (Fe73-9)

2. Economic Effects of Air Pollution on Electrical Contacts. R. C. Robbins. Holm Seminar on Electrical Contact Phenomena, 19th Annual Proceedings, Illinois Inst. of Technology, Chicago, Ill., October 15-18, 1973, pp. 80-86.

Prevention of contact failure in low voltage contacts is the largest problem area in which air pollution effects on electrical contacts are involved. Millions of low voltage contacts are used in computer and instrumentation circuits, and provision must be made to ensure their reliable and continued operation. The sulfur gases are primarily responsible for the deleterious effect of air pollution on these contacts. More money is spent in the protection of low voltage contacts against the effects of sulfur gases than in all the other problem areas combined. Protection of low voltage contacts against sulfur gases is accomplished in two general ways: the plating of contacts with precious metal and the use of air conditioning and air purification equipment.

3. The Damaging Effects of Air Pollution on Works of Art. J. Riederer. Proc. 3rd Intern. Union Air Pollut. Prev. Assoc. - VDI-Komm. Reinhaltung Luft Int. Clean Air Congr. (Duesseldorf, October 8-12, 1973), 1973, pp. A86-A89 (German).

The effects of air pollution are discussed on a number of works of art which are exposed to weathering or kept in museums. The effect of air pollution on stone, bronze and glass is much exaggerated, while on the other hand, little is known about the reactions of air pollutants with organic materials on museum objects also need more attention.

4. The Main Determinants of Atmospheric Patina Growth Rate and Quality Found on Copper and Copper Alloy Monuments. M. K. Kalish. Soobshcheniya, v. 28, 1973, pp. 274-319 (Russian).

The process of atmospheric patina growth is described for outdoor monuments made of copper and copper alloys. The influence of atmospheric moisture, corrosive impurities in the air, humidity, solid particles, and wind temperature is investigated as well as the influence of storage conditions, structure and composition of the alloy or metal, defects, surface quality and decorative treatment, construction features, and foreign materials.

5. The Role of Aerobic Bacteria in Metal Corrosion. J. Brison. Corrosion, Traitements, Protection, Finition, v. 21, No. 4, 1973, pp. 242-247 (French). (Fe73-23)

1972

1. Corrosion Damage on the Bronze Sculptures of the Residenz at Munich. J. Riederer. Deutsche Kunst- und Denkmalpflege, 1972, pp. 49-56 (German).

More than 50 bronze sculptures from the 16th century of the Residenz at Munich are exposed to weathering and accelerated by the action of air polluting gases. The metal from 32 sculptures was analyzed and it was found that bronzes rich in lead were the most extensively corroded. Various compounds of the patina were identified with X-ray diffraction techniques. The corrosion phenomena were studied with the metallographic microscope. Methods for cleaning and preservation are proposed.

2. Corrosion Damage to Bronze Sculpture. J. Riederer. *Werkst. Korros.*, v. 23, No. 12, 1972, pp. 1097-1100 (German).

In Germany more than 100 pre-19th century bronzes are still in the open, exposed to weathering and the action of the aggressive components of the air. To investigate the effect of air pollution on outdoor bronzes, about 200 bronze sculptures were analyzed, in order to find out if the intensity of corrosion depends on the composition of the metal. It was found that lead-bronzes are attacked rapidly while Cu-Sn-Zn alloys (which have been used since the 19th century) are more resistant. The corrosion products were identified by X-ray diffraction techniques. With a metallographic study of cross sections through the layers of dirt, the corrosion products, and the metal, the course of corrosion could be deduced. To find efficient methods for protection, 90 bronze bars were covered with different lacquers, waxes, oils, and fats, and exposed to weathering in the center of Munich. The resistance of these coatings is tested continuously.

3. Corrosion of Copper, Aluminum, and Zinc Alloys in a Sulfur Dioxide Atmosphere. S. Kopczynski. *Ochrona przed Korozja*, v. 15, No. 6, 1972, pp. 149-154 (Polish). (A172-2)
4. Corrosion of Historical Monuments Made of Copper and its Alloys in Out-Of-Doors Exposition. J. Lehmann and W. Wolski. *Osrodek Dokumentacji Zabytkow*, Warszawa, 1972, pp. 95-117.

The Chemical Laboratory, National Museum in Poznan and the Institute of Magnetochemistry, Mickiewicz University, proceeded to an investigation of the corrosion of copper and copper alloys in out of doors exposure. This study was promoted by the Centre of Documentation of Relicts of the Ministry of Culture and Art. The experiments comprised microscopic metallographic, spectrographical, chemical, X-ray and diffractometric analyses. The specimens analyzed were chosen among copper, bronze and brass relicts in four localities in Poland, namely Poznan, Gdansk, Krakow and Lancut. The relicts were from thirty to over four hundred years old. Three were of copper, one of brass and one of bronze.

The experimental results were compared with data from literature. Informations concerning results of metallographic, physical and chemical, conservation and technical investigations were taken into account.

Information and opinions concerning the corrosion of relicts consisting of copper and its alloys in out-of-doors exposure can be found in literature from very ancient times. Among the options dating back to antiquity, those of Plinius and Vitruvius were taken into account and cited.

Scientific investigation of the corrosion of copper and its alloys began in the third decade of the XIX-th century. Initially, it dealt only with the external aspects of the problem. Corrosion products on the surface of copper and copper alloy relics were identified with the green sediments of the corrosion products occurring on copper utensils in use at that time. Both the former and the latter were known as verdigris and referred to by the term "aerugo", mentioned by Plinius and Vitruvius.

The contemporary identification of "aerugo" based on Vitruvius description concerning its production from metallic copper and vinegar raises no doubts. Investigations carried out in the latter half of the XIX-century showed the identification of corrosion products of copper and its alloys in out doors exposure, termed "patina" and verdigris, to be incorrect. On the basis of chemical and mineralogical analyses, the corrosion products i.e. patina were identified with basic cupric carbonate and referred to the minerals malachite and azurite. The mineralogical identification of the corrosion products with the minerals malachite, azurite and, later with cuprite, tenorite, covellite, atacamite, brochantite, antlerite, etc. was based on the similarity of outer features as well as on the content of characteristic elements or groups of elements.

The performing of accurate determinations exceeded the possibilities then available. To identify a mineral, it is necessary to obtain the exact stoichiometric proportions of its components, or to analyse a well grown crystal by optical methods. The corrosion products of copper and copper alloy antiquities always present mixtures of chemical compounds and therefore it is not possible to obtain a precise stoichiometric result. The latter could be obtained only accidentally. It is also impossible to find in the corrosion products such well grown crystals as could be used in a microscopic crystallographic identification.

5. Survey on the Metal Corrosion by Air Pollution: Effect of Glauber's Salt on Metals. T. Nagano, A. Hattori, T. Nagai, Y. Ukishima, Y. Nakai, and I. Iwasaki. Shizuoka-ken Eisei Kenkyusho Nenpo, No. 16, 1972, pp. 217-226 (Japanese). (Fe72-17)
6. The Deterioration of Metallic Works of Art by Atmospheric Corrosion. M. Leone. Metallurgia Italiana, No. 6, 1972, pp. 1-3.

The chemical composition of six well known Italian bronze monuments are tabulated as follows:

	Cu %	Sn %	Pb %	Zn %
Grifo del Palazzo dei				
Piori di Perugia.....	88.15	10.23	0.44	-
Leone del Palazzo dei				
Priori di Perugia.....	91.34	7.54	0.77	-
Porta di San Zeno - Verona				
Formelle I° Maestro.....	90.86	6.49	2.49	-
Formelle II° Maestro.....	79.83	0.07	6.31	13.56
Cavalli di San Marcon -Venezia...	97.22	1.22	1.04	-
Ghiberti - Porta del Paradiso				
del Battistero di Firenze.....	93.7	2.2	1.3	1.8

7. The Influence of the Relative Humidity and Corrosion Products on the Adsorption of Sulfur Dioxide on Metal Surfaces. T. Sydberger and N. G. Vannerberg. Corrosion Science, v. 12, No. 10, 1972, pp. 775-784. (Fe72-22)

1971

1. A Survey and Economic Assessment of the Effect of Air Pollutants on Electrical Components. ITT Electrophysics Laboratory, Columbia, MD., NTIS Report PB-204183, August 1971, 89 pp.

An assessment was made of the economic impact of air pollution on electronic components. To begin the study, electronic components were divided into eleven different categories as defined by the Department of Commerce. The manner and amount of damage from air pollutants that might have been expected in each of these component categories was assessed by surveying the literature describing pollutant material damage mechanisms. The expected effects were compared with the actual experience of major manufacturing companies which appeared to account for most of the sales in each category. Where the literature survey indicated that gaseous sulfur compounds, notably sulfur dioxide, should be expected to account for most of the damage to electronic components, interviews with manufacturers revealed that particulate matter actually was responsible for most of the electronic component and equipment malfunctions currently being experienced. The economic effects, which were represented by three cost categories, were applied to each component category and then summed to arrive at a total cost of about 15.5 million.

2. Atmospheric Corrosion of Metals. M. Arpaia. Atti Not. Assoc. Ital. Metall., v. 26, 1971, pp. 363-367 (Italian). (Fe71-5)
3. Atmospheric Tests. S. K. Coburn. Chapt. 17 in Handbook on Corrosion Testing and Evaluation, edited by W. H. Ailor, Electrochemical Society, Corrosion Monograph Series, J. Wiley, New York, N.Y., 1971, pp. 475-505. (Fe71-6)
4. Corrosion of Copper, Tin, and Their Alloys. H. Leidheiser, Jr. Chapter 1, John Wiley, New York, N.Y., 1971, pp. 3-27.

The corrosion of copper is dependent on the relative humidity, with sulfur dioxide being the major promoting factor under outdoor conditions. Indoors, or under sheltered conditions, the influence of H_2S or SO_2 may predominate. Corrosion of copper is dependent on how the initial film is formed; if formed in pure air it will resist corrosion in sulfide containing atmospheres. Copper panels exposed many hundred of years ago showed less corrosion than those exposed more recently. Analysis of the older films showed them to be predominantly copper sulfate. Corrosion data is presented for copper and its alloys exposed at various locations around the world.

5. Corrosion of Metals by Sulfur Dioxide. G. K. Singhanian, B. Lal, and B. Sanyal. *Labdev. Part A*, v. 9, No. 3 & 4, 1971, pp. 214-216. (Fe71-10)
6. Corrosion Resistance of Electrically Polished Copper and Brass. M. Parlapanski, R. Miteva, and S. Chilov. *Zashch. Metal.*, v. 7, No. 4, 1971, pp. 478-481 (Russian).

The stability of electrolytic Cu (97.83 percent) and brass (Cu 61.94, Zn 37.76, and Pb + Fe + Sn 0.3 percent) was examined in HCl, H_2SO_4 , HOAc, citric acid, and corrosive gas atmospheres. Specimens with a working surface of 15 cm^2 were polished, etched in 10 percent HCl, rinsed, and electrolytically polished in H_2PO_4 at 20° and 1.5 V for 20 minutes. The relative humidity of the corrosive gas atmospheres was kept at 98 percent, whereas the concentration of Cl, H_2S , SO_2 , NH_3 , NO and HCl varied from 0 to 20 percent. The results point to an increased resistance of polished specimens when exposed to liquid corrosive media regardless of their nature. This effect is especially pronounced in the case of H_2SO_4 and citric acid. Similar results are found for corrosion in gaseous media, the only exception being the corrosion of brass in atmospheres containing 3-20 percent SO_2 .

7. Evaluation of Atmospheric Factors by Analyses of Corrosion Products and Surface Deposits on Copper Plates. H. Abe, Y. Ishii, and H. Kato. *Quarterly Reports, Railways Technical Research Institute*, v. 12, no. 3, 1971, pp. 170-174.

With the purpose of investigating atmospheric pollutants by physical and chemical analysis of corrosion products and deposits on the surface of metals, exposure tests of copper specimens have been carried out for two years at different contaminated sites. As a result of measurements, corrosion products in the atmosphere could be successfully grouped: sulfide-, basic sulfate-, and basic chloride-group. Sulfide is most detrimental to copper alloys. Principal deposits on the specimens are soil, ferric oxide particles, and sodium chloride. The ratio of weight loss due to corrosion to weight difference between before and after the exposure could be a measure of contamination rate.

8. Relation of Airborne Nitrate to Telephone Equipment Damage. H. W. Hermance, C. A. Russell, E. J. Bauer, T. F. Egan, and H. V. Wadlow. *Environmental Science and Technology*, v. 5, No. 9, 1971, pp. 781-789.

Airborne nitrates cause stress corrosion cracking of nickel-brass telephone parts--particularly relay wire springs in the Los Angeles area. A survey of nitrate accumulation on equipment was made in California and other locations. Nitrate deposits were transferred to paper disks and determined spectrophotometrically with chromotropic acid. Nitrate deposition correlated with relay failure and a rating was established to estimate the degree of danger to equipment. A correspondence to the general patterns of smog and air pollution existing in California was indicated. Several eastern locations are marginal and some nitrate-caused

component problems have occurred, but no relay failures. Air filtration and humidity control provide protection against the nitrate-caused failures.

9. Technical-Economic Evaluation of Air-Pollution Corrosion Costs on Metals in the U.S. F. W. Fink, F. H. Buttner, and W. K. Boyd. NTIS Report PB-198453, February 19, 1971, 160 pp. (Fe71-25)
10. The Destruction of Works of Art by Air Pollution. J. Riederer. *Schonere Heimat*, v. 60, 1971, pp. 44-47 (German).

Works of art, exposed outdoors, which consist of stone, glass or metal are seriously damaged or already destroyed by air pollution. The decay of stone and glass, which also suffer from natural weathering, proceeds so rapidly that conservation using available, although not yet entirely convincing methods, should perhaps wait until better techniques are developed. In addition to stone conservation, the Doerner-Institute also investigates damages to bronze by air pollution, in order to develop restoration-methods for the great number of bronzes of the 16th century which are still outdoors in many German towns. For the protection of modern bronzes, coatings of wax or synthetic materials are tested.

1970

1. Atmospheric Corrosion of Copper and Copper-Base Alloys During Twenty Years' Exposure in a Marine and an Industrial Environment. I. R. Scholes and W. R. Jacob. *J. Inst. Metals*, v. 98, 1970, pp. 272-280.

To assess the long-term behavior of copper and copper alloys during atmospheric exposure, panels of twenty-one different materials have been exposed in a marine atmosphere at Ardeer on the West Coast of Scotland and in an industrial atmosphere at Witton, Birmingham. Panels were examined visually during exposure and detailed examinations for nature and extent of patina formed, corrosion effects, and change in mechanical properties were carried out after twenty years' exposure. Duplicate panels of ten materials were examined for weathering and localized corrosion effects after five years' exposure. Results of these examinations have shown that the most uniform patina was formed on copper and, with the exception of 95/5 phosphor bronze, the presence of alloying elements had a deleterious effect. The rate of penetration was least for unalloyed copper and the industrial atmosphere was about twice as aggressive as the marine environment, but stifling had occurred in both environments. Generally, changes in mechanical properties were small and there was some correlation between reduction in ductility and localized corrosion effects.

2. Atmospheric Pollution and Historic Buildings. A Contemporary Urban Problem. C. Berindan. *Centre Belged'Etude et de Documentation des Eaux*

(Tribune de), v. 23, No. 324, November 1970, pp. 498-503 (French).
(Fe70-4)

3. Corrosion Behavior of the Major Architectural and Structural Metals in Canadian Atmospheres. Summary of Ten-Year Results of Group I.
E. V. Gibbons. Nat. Res. Council Can., Div. Bldg. Res., Tech. Paper, No. 328, 1970, 21 pp. (Fe70-5)
4. Corrosion of Building Materials. A. Valeriana de Seabra and M. Cravo. Tecnica (Lisbon), v. 32, 1970, pp. 493-512 (Portuguese). (Fe70-6)
5. Design and Monitoring of Multiple and Varying Pollutant Concentration.
E. Bassett, H. Frankel and R. Grenley. Preprint (Presented at the American Chemical Society Meeting, Division of Water, Air and Waste Chemistry, Chicago, Ill., September 13-18, 1970), Div. of Water, Air and Waste Chemistry, American Chemical Society, Washington, D. C., 1970, pp. 93-98.

A variety of environments were simulated to study their effects on the reliability of electronic components. The atmospheres ranged from the reducing atmosphere of the northeast to the oxidizing atmosphere of Los Angeles. Industrial atmospheres using such corrosive gases as chlorine and easily decomposed gases (such as hydrogen sulfide) were also simulated. A major component of the simulation system was a gas chromatograph, while the environmental chambers were analyzed by a vacuum technique that maintains a continuous flow of gas for sampling.

6. Inquiry Into the Economic Effects of Air Pollution on Electrical Contacts.
R. C. Robbins. SRI Project PSU-7345, Final Report, Stanford Research Institute, April 1970, 39 pp. (Al70-4)
7. Natural Patination of Copper. M. Schmidt. J. Inst. Metals, v. 98, 1970, p. 238.

Atmospheric tests (1962-1969) on common copper showed that neither the type of copper, nor its hardness, nor its surface roughness significantly affected the rate of natural patination. This depends primarily on the total time of exposure to corrosive water. Inclined surfaces dry more slowly than vertical surfaces after rain, and are also subjected to attack by dew. The composition of the corrosion products on the inclined samples fitted $\text{CuSO}_4 \cdot 6\text{Cu}(\text{OH})_2$. The rainwater collected in Copenhagen in 1965 had a pH at 4 to 5, owing to the increased atmospheric pollution with sulfur dioxide. This accelerated natural patination 3 to 4-fold in comparison with the rate in the 1930's when rainwater pH was 6 to 8.

8. Properties of Electrolyte Films Formed Through Atmospheric Corrosion.
D. Knotkova-Cermakova and J. Vlckova. Werkst. Korros., v. 21, No. 1, 1970, pp. 16-21 (German). (Fe70-10)

9. Reaction Between SO_2 and Wet Metal Surfaces. N. G. Vannerberg and T. Sydberger. Corrosion Science, v. 10, 1970, pp. 43-49. (Fe70-11)
10. Relation of Air-Borne Nitrate to Telephone Equipment Damage.
H. W. Hermance, C. A. Russell, E. J. Bauer, T. F. Egan and H. V. Wadlow. Preprint (Presented at the American Chemical Society, Division of Water, Air and Waste Chemistry, Chicago, Illinois, September 13-18, 1970), Division of Water, Air and Waste Chemistry, American Chemical Society, pp. 113-117.

In 1959, nickel brass wire springs supporting contacts on telephone relays began breaking off in the Los Angeles area. This breakage was found to be due to a stress corrosion cracking when the wire spring was anodic because of nitrates present in dusts deposited by the surrounding air. Laboratory tests showed that the crack growth was very slow at relative humidities of less than 50%. It was therefore decided to maintain humidities below this level in susceptible locations and to install 95% National Bureau of Standards rated filters to combat further dust accumulation. Nitrate deposition was measured. Representative relays were sampled in the various central offices in the Los Angeles area. The offices were then given a nitrate rating based on the average accumulated nitrates per unit area with a factor to adjust for the length of exposure in service. Nitrate accumulations in several other cities with known dust and pollution problems were measured. Other types of equipment using nickel-brass components were also affected.

11. Systems Analysis of the Effects of Air Pollution on Materials.
R. L. Salmon. NTIS Report PB-209192, January 15, 1970, 196 pp. (Fe70-13)
12. The Corrosion of Copper, Tin, and Their Alloys--Part I. H. Leidheiser, Jr. J. Wiley, New York, N.Y., 1970, pp. 3-27.

The controlling factor for corrosion of copper in the atmosphere is moisture (relative humidity), while the promoting factor is sulfur dioxide. Preoxidation of copper in pure air tends to reduce tarnishing in sulfide-containing atmospheres. Corrosion rates for copper and copper alloys are reported for varied locations around the world, and the relative corrosivity of 25 test sites are also reported. In addition, methods for protecting copper in the atmosphere and controlling bronze disease are given.

13. The Weathering and Performance of Building Materials. J. W. Simpson and P. J. Horrobin. Medical and Technical Publishing Co., Ltd, 1970, 277 pp. (Fe70-17)
14. Use of Environmental Data in Atmospheric Corrosion Studies.
J. F. Stanners. Brit. Corros. J., v. 5, No. 3, 1970, pp. 117-121. (Fe70-18)

1969

1. Calculation of Moistening and Metallic Corrosion in Atmospheric Environment. A. I. Golubev and M. Kh. Kadyrov. Proc. 3rd Intern. Congr. on Metallic Corrosion, Moscow (1966), Swets-Zeitlinger, Amsterdam, Holland, v. 4, 1969, pp. 522-531. (Fe69-24)
2. Corrosion in the Atmosphere. P. Atterby. NTIS Report N71-26259, November 1969, 9 pp. (Swedish). (Fe69-25)
3. Corrosion of Metals in the Tropics. B. Sanyal, G. K. Singhanian, and J. N. Nanda. Proc. 3rd Intern. Congr. on Metallic Corrosion, Moscow (1966), Swets-Zeitlinger, Amsterdam, Holland, v. 4, 1969, pp. 542-543. (Fe69-26)
4. Evaluation of Atmospheric Corrosion Tests With Iron, Copper, and Zinc Extending Over Three Years, at Czechoslovak Testing Stations. K. Barton and Z. Bartonova. Werkst. Korros., v. 20, No. 2, 1969, pp. 87-93. (German). (Fe69-30)
5. Studies on Corrosion of Metals Provoked by Gaseous Pollutants. B. Sanyal, G. K. Singhanian, and D. V. Bhadwar. Proc. 3rd Intern. Congr. on Metallic Corrosion, Moscow (1966), Swets-Zeitlinger, Amsterdam, Holland, v. 4, 1969, pp. 454-464. (Fe69-36)

1968

1. Atmospheric Corrosion of Copper Alloys. D. H. Thompson. Metal Corrosion in the Atmosphere, ASTM STP 435, American Society for Testing and Materials, 1968, pp. 129-140.

Specimens of 18 copper metals were exposed outdoors in four locations for periods of two and seven years. Corrosion damage was assessed by measurement of loss in weight, loss in mechanical properties, and depth of pitting. Weight loss is shown to be the best measure of uniform corrosion. The mean corrosion rate was on the order of 0.05 mils per year (mpy) (1.3 mm/year). Greatest corrosion occurred at the industrial site, followed by east coast marine, west coast marine, and the rural site. Nickel improved the atmospheric corrosion resistance of the copper alloys tested. Results are comparable to those obtained in other similar tests.

2. Copper and Copper Alloys. E. Mattsson and R. Holm. Metal Corrosion in the Atmosphere, ASTM STP 435, American Society for Testing and Materials, 1968, pp. 187-210.

In 1958, exposure tests were started in Sweden to gain knowledge of the natural patination and the corrosion behavior of copper and copper alloys when used outdoors. The investigation covered 36 alloys in sheet

or rod form: 5 coppers, 20 brasses, 5 phosphor bronzes, 1 silicon bronze, 1 aluminum bronze, 1 cadmium bronze, 2 nickel-silvers, and 1 free-cutting phosphor bronze. Specimens were exposed in rural, marine, and urban atmospheres. After two- and seven-years' exposure, specimens were examined.

During the first years of atmospheric exposure, the copper and copper alloys acquired a dark surface coating consisting mainly of copper oxide (Cu_2O). In urban and marine atmospheres, signs of green patina appeared on copper after about six to seven years; the basic copper salt causing the green color being sulfate in the urban, chloride and sulfate in the marine atmosphere. The average penetration as calculated from the weight loss during 7-years' exposure was: in rural atmosphere 0.2 to 0.6 μm per year, in marine atmosphere 0.6 to 1.1 μm per year, in urban atmosphere 0.9 to 2.2 μm per year. The corrosion rate decreased with the time of exposure. The losses in mechanical properties were in most cases of negligible importance.

The dezincification of brass was of significant degree only in β -brass and in certain $(\alpha + \beta)$ -brasses when exposed to the urban or the marine atmosphere. Dezincification was observed also in α -brass, even with as high copper content as 92 percent, although the depth of attack was not very great. It should also be mentioned that arsenic was consistently effective as a dezincification inhibitor for α -brass only in the marine atmosphere. This indicates that the mechanism of dezincification is different in the presence and in the absence of chloride.

The tests described here are continued and further examinations will be carried out after 20 years of exposure.

3. Corrosion of Metals by Aqueous Solutions of the Atmospheric Pollutant Sulfurous Acid. W. McLeod and R. R. Rogers. *Electrochem. Technol.*, v. 6, No. 7-8, July-August 1968, pp. 231-235. (Fe68-3)
4. High Pressure Electrical Contacts. J. King. *Proc. 1968 Electrical Components Conference*, May 8-10, 1968, pp. 454-458. (Fe68-9)
5. Increased Connector Contact Reliability. M. Ball, F. H. Hardie and E. J. Struckus. *The Electronic Engineer*, March 1968, pp. 82-85. (Al68-6)
6. Investigations of the Corrosion-Causing Properties of Volatile Acids and Anhydrous Acids. E. Iaengle. *Eidgenoessische Technischen Hochschule, Zurich, Switzerland. Ph.D. Thesis*, 1968, 43 pp. (German). (Fe68-11)
7. Measurement of Atmospheric Factors Affecting the Corrosion of Metals. H. Guttman and P. J. Sereda. *Metal Corrosion in the Atmosphere*, ASTM STP 435, American Society for Testing and Materials, 1968, pp. 325-359. (Fe68-12)

8. Mechanism and Kinetics of Corrosion in a Moist Atmosphere in the Presence of Hydrogen Chloride Vapors. K. Barton and Z. Bartonva. Tr. Mezhdunar. Kongr. Korroz. Metal., 3rd (1966), edited by N. D. Lesteva, Izd. "Mir," Moscow, USSR, v. 4, 1968, pp. 493-506 (Russian). (Fe68-13)
9. Patina on Old Metal Objects. J. Lehmann. Monographs of the National Museum in Pozan, v. 2, 1968, pp. 1-125 (Polish). (Fe68-15)
10. Tarnishing and Contamination of Metals. W. E. Campbell and U. B. Thomas. Proc. Engineering Seminar on Electrical Contact Phenomena, Illinois Inst. Technology, Chicago, Ill., November 11-15, 1968, pp. 233-265.

If the voltage across a contact at make or break is less than the lowest fritting voltages which have been encountered experimentally, that is, less than 0.03 volts, problems in reliability are greatly increased. Contacts operating in this manner are the concern of this report. Under these conditions it is possible for insulating films to build up to a thickness sufficient to cause serious contact noise as well as to cause failure by open circuit. The contaminants which are found on electrical contacts are of many kinds.

11. The Composition and Structure of Natural Patinas. Part 1 - Copper and Copper Alloys. Section B - 1930 to 1967. S. Z. Lewin and S. M. Alexander. Art Arch. Tech. Abst., v. 7, No. 1, 1968, pp. 277-370.

A comprehensive collection of abstracts for papers published from 1930 through 1967 on the composition and structure of natural patinas on copper and copper alloys is presented.

1967

1. Corrosion by Air Pollution. J. R. Goss. Proc. Annu. Conf., Nat. Soc. Clean Air, No. 34, 1967, pp. 75-92. (Fe67-4)
2. Ingress-Limited Corrosion of Contacting Surfaces. R. F. Snowball, J. B. P. Williamson, and R. C. Hack. IEEE Transactions, v. PMP-3, No. 3, September 1967, pp. 82-88.

The most pressing problem in electric contact testing is to define the modes by which contacts fail. Until we understand why and by what mechanism contact spots stop passing electricity between the mating members, it will be impossible to devise relevant life-testing procedures. This paper describes an experimental technique whereby interfaces can be observed during exposure to moist, polluted air and the degradation of contact spots studied in situ. The reactions that occur are analyzed in terms of the physical effects of the ingress of reactants into contact joints, and the resistance changes observed. The main experimental tool was metallography, including macro- and micro-cinephotography. The dis-

inction between ingress-limited corrosion and reaction-limited corrosion is introduced, and the death of contact spots is observed under the microscope. This technique makes possible the direct observation of the progressive corrosion of an array of contact spots, and reveals in detail how the conducting area of each spot is eroded by the chemical action.

3. Mechanism of the Corrosion of Fe, Zn, and Cu in a Humid Atmosphere Containing HCl Vapors. K. Barton and Z. Bartonova. Collect. Czech. Chem. Commun., v. 32, No. 7, 1967, pp. 2431-2438 (German). (Fe67-6)
4. Surface Properties Key to Contact Selection. J. C. Chaston. Mat. Eng., v. 66, No. 8, 1967, pp. 76-77.

In light-duty electrical contact applications metals that do not tarnish are preferred therefore only gold, platinum and rhodium plating used. With traces of sulfur in the air silver readily tarnishes and silver sulfate is an excellent insulator at low voltages. Also at low voltages organic vapors tend to form polymers in the presence of metals, except gold and platinum. At slightly higher voltages, the contacts become self cleaning and silver and copper can be used. Under medium voltages where welding is the problem, palladium and its alloys, platinum alloys, tungsten, nickel-silver, and silver-cadmium oxide have to be used. Under heavy duty conditions where the contacts are air-cooled tungsten-silver should be used.

5. The Composition and Structure of Natural Patinas: Part 1 - Copper and Copper Alloys. Section A - Antiquity to 1929. S. Z. Lewin and S. M. Alexander. Art Arch. Tech. Abst., v. 6, No. 4, 1967, pp. 199-283.

A comprehensive collection of abstracts for papers published to 1929 on the composition and structure of natural patinas on copper and copper alloys is presented.

1966

1. Atmospheric Corrosion of Metals at Bhavnagar. V. S. Rao. Indian J. Technol., v. 4, No. 5, 1966, pp. 159-161. (Fe66-3)
2. Atmospheric Corrosion of Steel, Zinc, Cadmium, Copper, and Aluminum in Different Coastal and Continental Regions. G. K. Berukshtis and G. B. Klark. Corrosion of Metals and Alloys, Collection No. 2, Israel Program for Scientific Translations, Jerusalem, 1966, pp. 281-297. (Fe66-4)
3. Combating the Effects of Smog on Wire Spring Relays. H. W. Hermance. Bell Laboratory Record, February 1966, pp. 48-52.

For many years, nickel brass (an alloy of copper, zinc, and nickel) has been used with excellent results in wire-spring relays and other switching equipment in central offices all over the country. Some time ago, however, central offices in the Los Angeles area reported that the nickel brass wire springs in some relays had developed stress-corrosion cracking, apparently because of a combination of physical stress and chemical corrosion. The problem appeared to be unique to California and especially to Los Angeles--there was no record of it having happened in any other part of the country.

4. Corrosion Behavior of Salt Powder Towards Various Metals. A. Bukowiecki and B. G. Joshi. Schweiz. Arch. Angew. Wiss. Tech., v. 32, No. 2, 1966, pp. 42-54. (Fe66-5)
5. Corrosion Behavior of Some Metallic Materials in Liquid Sulfur Dioxide. L. Rivola, T. Bazzan, M. Piro, and G. Bombara. Proc. 2nd Intern. Congr. Metal. Corrosion, New York, (1963), National Association of Corrosion Engineers, Houston, TX, 1966, pp. 418-423. (Fe66-6)
6. Cracking Tendency and Mechanical Properties of Silicon Brasses. A. V. Bobylev and Y. P. Manzienko. Tsvet. Metal., v. 39, No. 9, 1966, pp. 82-86 (Russian).

The cracking corrosion resistance of ordinary brass containing, Cu 63 and 68 percent, and of Si brass containing Cu 68-85 and Si 0.5-2.1 percent was examined by exposure to ordinary, NH_3 -containing, and SO_2 -containing atmosphere, and to $\text{Cu}(\text{NO}_3)_2$ solution. Addition of Si 2 and increasing the Cu content to 85 percent enhanced markedly the cracking corrosion resistance, and addition of Al to the Si brass impaired it in NH_3 -containing atmosphere. The Si brass had higher mechanical strength, ductility, and hardness than the ordinary brass even after annealing at 300° .

7. Current Ideas in the Philosophy of Testing Electrical Contacts. H.B. Ulsh. IEEE International Convention Record, v. 14, No. 9, 1966, pp. 35-38.

The test methods and procedures discussed in this paper may appear to be elaborate and expensive, but in computer equipment, the number of connector type contacts alone require a very reliable component. Also, since contact failures are generally intermittent, they are difficult to troubleshoot and service.

With the continued advancement in contact technology in the areas of physics and chemistry of surfaces, in cause-effect relationships of air pollution on contact materials, and in the understanding of failure mechanisms, better test methods should develop.

8. Tarnish Films on Electric Contact Materials. R. V. Chiarenzelli. Proc. Third Intern. Research Symposium on Electrical Contact Phenomena, June 6-10, 1966, pp. 85-93.

The paper describes accelerated laboratory and field tests conducted on copper, nickel, gold, and silver to determine the effects of atmospheric weathering on the formation of tarnish films. Data on film thickness and contact resistivity are given.

9. The Effects of Air Pollution on Electrical Contact Materials.
R. V. Chiarenzelli and F. L. Joba. J. Air Pollution Control Assoc., v. 18, No. 3, 1966, pp. 123-127.

A long-term field and laboratory program for testing the effects of air pollutants on electrical contact materials is reported.

1965

1. Alarm for the Bronze Horses of St. Marks in Venice. P. Rotondi. 1st Centrale de Restauro, Boll., 1965, pp. 6-20.

The author calls to the attention of competent authorities the progressive corrosion of the four famous bronze horses, as revealed by examination of cross-sections. The gilded metal surfaces are covered with crystals of basic copper sulfate resulting from atmospheric corrosion and intensified by air pollution due to the industrialization of the Porto Marghera district and to the spreading of domestic heating with kerosene in Venice. The paper is illustrated by photographs of corrosion products and cross-sections. Different types of corrosion appearing in various areas of sculptures are shown.

2. Atmospheric Corrosion Products of Some Commercial Metals. H. J. Meyer. Korrosion, No. 17, 1965, pp. 44-52 (German). (Fe65-3)
3. Significance of Corrosion Testing Process with Special Consideration of the SO₂ Test According to DIN 50018. W. Kesternich. Werkst. Korrosion, v. 16, 1965, pp. 193-201 (German). (Fe65-15)
4. The Significance of Sulfur Dioxide in the Atmospheric Corrosion of Metals. G. Schikorr. Korrosion, No. 17, 1965, pp. 27-34 (German). (Fe65-20)

1964

1. An Electrical Resistance Method for Measuring Rates of Corrosion of Electrodeposited Metals in Laboratory Tests. F. Enrico, V. Riccio, and B. Martini. Product Finishing, v. 17, No. 5, May 1964, pp. 74-79.

The rates of corrosion of detached foils of electrodeposited nickel, copper, zinc and cadmium in sulfur dioxide and salt spray tests have been obtained by measurement of changes in the electrical resistance of the

test-pieces. The method has been found to be of practical value and is very sensitive but it has the disadvantage that at its present state of development it can only be applied to detached coatings and any effects associated with a basis metal are therefore not revealed. The results obtained have been consistent with those previously found in other ways for the coatings and corrosive environments studied. Dull and semi-bright nickel were corroded faster than bright high-sulfur nickel. Cadmium behaved better than zinc.

2. Atmospheric Corrosion of Copper and Copper Alloys. W. Wiederholt. Werkst. Korros., v. 15, No. 8, August 1964, pp. 633-644 (German).

The atmospheric corrosion of copper and copper alloys is summarized on the basis of the literature. This includes the formation of protective coatings, particularly patina, in dry and wet atmospheres, the composition of corrosion products, the effect of material-based variables on corrosion, and the artificial production of patina.

3. Atmospheric Effects on Friction and Wear. W. E. Campbell. Machine Design, August 27, 1964, pp. 186-192.

Friction and wear of metals are greatly influenced by interaction at the rubbing interface with constituents of the air. Interactions of principal interest are:

1. Adsorption and reaction of oxygen.
2. Adsorption and reaction of water.
3. Adsorption and reaction of products of combustion.
4. Two or more of these interactions combined.

Friction and wear, under conditions generally prevailing in bearing operation, result to a large extent from the making and shearing of adhesion bonds between surface atoms. The bond-shearing results in a temperature increase at the surface which increases the oxidation rate of the virgin metal thus exposed.

These interactions can also influence friction and wear by other processes dependent on these primary actions. For example, electron emission accompanies disruption of oxide films on base-metal surfaces. Also, a catalytic process causes modification of adsorbed organic films to produce solid polymeric films on the surface.

All these reactions are factors in boundary lubrication and in friction wear. This article reviews some of the important effects.

4. The Influence of Sulphur Dioxide on the Atmospheric Corrosion of Metals. G. Schikorr. Werkst. Korros., v. 15, No. 5, 1964, pp. 457-463. (Fe64-4)

1963

1. Coloring and Finishing of Copper Metals. D. H. Osborne and J. M. Foehl. Construction Specifier, October 1963, pp. 50-55.

The color spectrum afforded by the architectural alloys of copper both in the natural and weathered states is discussed. Research and development projects provide new and improved methods for the preservation of the natural colors of the metals as well as simpler, more reliable means for accelerating the development of both the statuary colors and the patinated effects.

1962

1. Atmospheric Corrosion by Electrolyte Nuclei. B. Sanyal and D. V. Bhadwar. J. Sci. Industr. Res., v. 21D, 1962, p. 243. (Fe62-2)
2. Corrosion of Copper Alloys in Ozone-Containing Air. R. G. Malkina. Vestn. Tekhn. i Ekon. Inform. Nauchn.-Issled. Inq. Tekhn.-Ekon. Issled. Gos. Kom. Sov. Min. SSSR po Khim., v. 5, 1962, pp. 44-45 (Russian).

Results of a study of corrosion of alloys of copper-7 percent aluminum and copper-5 and 9 percent tin are given. The ozone content of the air was 1-1.2 percent by volume. The copper-tin alloy with 5 percent tin was the least corrosion resistant. Corrosion of copper-tin alloys slows down, and that of copper-aluminum alloys increases with time.

3. Corrosion of Metals in an Atmosphere of Sulfur Dioxide. V. G. Gleim, G. F. Potemkin, E. M. Lavrova, and S. G. Tereshchenko. Inst. Nefti Khim., 1962, pp. 287-290 (Russian). (Fe62-4)
4. Electrical Contact Materials: Properties and Selection. E. Freudiger. Electro-Technology, v. 69, 1962, pp. 72-78.

The degree of electrical resistance or, conversely, conduction between two surfaces designed to make or break an electrical circuit is limited by the mechanical qualities and resistivities of the materials. Basically, in a contact system, there are three controlling factors or conditions:

1. Bare metallic contacts where the continuity of current flow is assured by the nature of the material.
2. Contacts between surfaces covered with an adsorbed layer in the magnitude of a few molecular diameters, where electrical flow may be slightly limited due to the impurity adsorbed.
3. Coherent foreign films or individual large particles, both consisting either of insulators (oil, plastics, fibers) or semiconductors (oxides, sulfides) which act as limiting factors in conduction.

5. Improving Contact Reliability in Low-Level Circuits. J. J. McManus. Electro-technology, v. 69, 1962, pp. 98-101.

Methods used in telephone and telegraph circuits, particularly where low-level transistor switching is involved, may have wider application. They include choice of nonfilm-forming contact materials and use of supplementary "wetting" voltages to break down high resistance films.

6. The Possibilities of Increasing the Resistance of Steel Against Atmospheric Corrosion. K. Barton. Intern. Symp. Anti-Corrosion Protect. Bratislava, v. 1, 1962, 8 pp. (Fe62-8)

1961

1. Atmospheric Corrosion. U. R. Evans. Chapt. 8 in The Corrosion and Oxidation of Metals, Edward Arnold, 1961, pp. 481-535. (Fe61-2)
2. Corrosion in Buildings, P. J. Sereda. Canadian Building Digest, Report No CBD-20, August 1961, 4 pp. (Fe61-5)
3. Effects of Atmospheric Contamination on Switching Noise. J. Bloomberg and W. E. Campbell. Proc. Engineering Seminar on Electrical Contacts, Pennsylvania State University, University Park, Pa, June 11-15, 1961, pp. 95-107.

This report is based on work carried out for the purpose of understanding the cause and developing a simple palliative for infrequent but objectionable noise or voltage fluctuations originating in the contacts of a specific switch. Because of the statistical nature of the phenomenon and the developmental character of the problem, the data are not always as logical and complete as might be desired. In spite of some inconsistencies, they give a picture of sliding base-metal contact behavior that accords with published information on other switching systems and with limited field studies on the subject switch. They also afford new information on noise and wear behavior which is believed to advance general understanding. The results discussed here are representative of the important principles established.

1960

1. Chemical Resistance to Ammonia of Construction Materials. A. E. Missan. Trudy Gosudarst. Inst. Priklad. Khim., v. 44, 1960, pp. 112-127 (Russian). (Fe60-3)
2. Corrosion of Copper in Ozonated Air. R. G. Malkina. Trudy Moskov. Inst. Khim. Mashinostroeniya, v. 22, 1960, pp. 51-62 (Russian).

Corrosion products which formed on polished copper during exposure to a stream of ozonated air were weighed and were identified by X-ray diffraction. Rates of corrosion increased with O_3 content, temperature, and moisture in the air. At -40 to -30° little reaction occurred. Weight gain (y , mg/sq.cm) in dry ozonated air followed a parabolic law with time (t , hrs). At 0° , $y = 0.018t^{0.44}$ for 1.1-1.3 percent O_3 , and $y = 0.015t^{0.40}$ for 0.5-0.7 percent O_3 . Data scattered more at room temperature, where $y = 0.02t^{0.74}$ and $y = 0.23t^{0.45}$ for 1.1-1.3 and 0.5-0.7 percent O_3 , respectively. In the presence of moisture, corrosion at room temperature followed, respectively, exponential laws $y = 0.023\exp(0.23t)$ and $y = 0.01\exp(0.38t)$, when H_2O vapor was 6 and 12-15 mg/l in air containing 1.1-1.4 percent O_3 . At 60° with 1.1-1.2 percent O_3 and 6 mg H_2O/l , $y = 0.02\exp(0.20t)$. Rise of O_3 content to 1.4 percent resulted in formation of CuO along with Cu_2O , even at 0° and room temperature. Hydrated CuO formed when the air was saturated with moisture.

3. Evaporated Metal Films As Indicators of Atmospheric Pollution. J. P. Lodge, Jr., and B. R. Havlik. Int. J. Air Pollution, v. 3, No. 4, 1960, pp. 249-252. (Fe60-4)
4. Theory of Atmospheric Corrosion of Metals. N. D. Tomashov. Trudy Inst. Fiz.-Khim., Akad. Nauk S.S.S.R., No. 8, 1960, pp. 14-40 (Russian). (Fe60-7)

1959

1. Corrosion of Metals in Synthetic Atmospheres Containing Sulfur Dioxide. B. Sanyal and D. V. Bhadwar. J. Sci. and Ind. Research (India), v. 18A, February 1959, pp. 69-74. (Fe59-3)
2. Design and Interpretation of Atmospheric Corrosion Tests. H. R. Copson. Corrosion, v. 15, No. 10, October 1959, pp. 533t-541t. (Fe59-4)
3. Deterioration of Materials in Polluted Atmospheres. J. E. Yocum. Corrosion, v. 15, No. 10, October 1959, pp. 541t-545t. (Fe59-5)
4. Mechanism by Which Non ferrous Metals Corrode in the Atmosphere. P. M. Aziz and H. P. Goddard. Corrosion, v. 15, No. 10, 1959, pp. 529t-533t. (Al59-3)
5. Reaction Mechanism for the Atmospheric Corrosion of Metals in Damp and Sulfur Dioxide-Containing Air. K. Barton and E. Beranek. Werkst. Korros., v. 10, 1959, pp. 377-383. (Fe59-7)

1958

1. Copper Alloys for Corrosion Resistance. R. V. L. Hall. Chem. Eng. Progr., v. 54, 1958, pp. 51-55.

A review of corrosion rates, dezincification, stress corrosion, cracking, and fatigue related to Cu alloys.

2. Influence of Dust and the Atmospheric Corrosion of Metals. K. Barton. Werkst. Korres., v. 9, Aug-Sept 1958, pp. 547-549 (German). (Fe58-7)
3. Staining of Copper and Brass. E. Mattsson. Corrosion, v. 14, 1958, pp. 88t-92t.

Copper alloys are known for their fine luster and high resistance to corrosion, but they tarnish under certain conditions. A surface oxidation of the metals normally occurs under the influence of the atmosphere. At elevated temperatures this process may result in colored, so-called-temper films; in the presence of H_2S such films may occur at room temperature. When copper alloys are exposed to the outdoor atmosphere a black film will soon form on the surface, usually changing to a pleasing green patina after some years. Ugly dark stains (water stains) are formed when copper-base material is left in contact with stationary water for a lengthy period. Such water damage may be caused by rain or condensed moisture in transit or in storage. A similar staining is caused by hygroscopic surface impurities. Typical examples are chlorides from tap water that has evaporated on the metal surface, solder (flux) residues, hand perspiration, H_2SO_4 , and dust. Copper alloys can be protected from corrosion by passivating inhibitors, slushing compounds, lacquers, or proper packaging.

4. The Corrosion of Metals and Metal Castings in Industrial Atmospheres. G. Schikorr. Schweiz. Arch. angew. Wiss. Techn., v. 24, No. 2, 1958, pp. 33-46. (Fe59-9)

1957

1. Atmosphere Affects the Stress-Corrosion Failure of High Brass. C. H. Hannon. Corrosion, v. 13, 1957, pp. 417t-418t.

Observed failures of high brass parts (70-30 yellow brass) after prolonged service as arcing gap electrodes in electrical appliances led to a laboratory investigation. Failure of the electrodes was evidenced by disintegration, embrittlement, cracking, and obvious oxidation. In laboratory tests of highly stressed specimens, rapid failure occurred in NH_3 atmospheres but not in mixtures of NH_3 and O_3 , or O_3 alone. No evidence of cracking was observed in either O_3 or N_2O .

2. Determination of the Corrosion Power of the Atmosphere.
N. D. Tomashov and G. K. Berukshtis. Trudy Inst. Fiz. Khim., Akad. Nauk S.S.S.R., No. 6, Novye Metody Fiz. Khim. Issledovaniy, No. 2, 1957, pp. 50-55 (Russian). (Fe57-3)
3. The Effects of Air Pollution on Buildings and Metalwork. R. J. Schaffer. Air Pollution, edited by M. W. Thring, Butterworth Scientific, London, 1957, pp. 58-71.

This paper discusses the effects of sulfur dioxide, chloride, ammonium and particulate matter on the corrosion and deterioration of materials. It also presents some historical information of interest on air pollution.

1956

1. Corrosion Studies. X. The Mechanism of the Atmospheric Corrosion of Metals in Moist Atmospheres Contaminated With Sulfur Dioxide.
K. Barton and E. Beranek. Chem. Listy, v. 50, 1956, pp. 1388-1398. (Fe56-6)
2. Effect of Natural Atmospheres on Copper Alloys, 20-Year Test.
A. W. Tracy. Atmospheric Corrosion of Non-Ferrous Metals, ASTM STP 175, American Society for Testing and Materials, 1956, pp. 67-76.

The ASTM Committee B-3 tests of 11 copper alloys exposed at industrial, marine, and rural sites for periods up to 20 years are discussed. In most atmospheres, copper and its alloys form a thin, adherent, stable film corrosion products which eventually limits the rate of corrosion to the rate of solution of the film. Certain copper-zinc alloys undergo dezincification corrosion; the metal is dissolved as alloy and copper replated. Brasses containing about 15 percent or less of zinc are highly resistant to dezincification. Tin in admiralty metal probably has some inhibiting effect on dezincification, but not enough for many corrosive conditions. As, Sb, or P in amounts of approximately 0.04 percent are now added to admiralty metal and effectively inhibit dezincification. Of the copper alloys, the high-zinc brasses are most subject to stress-corrosion cracking in the presence of NH_3 and moist air. Residual stress, remaining from cold-working operations, should be eliminated by heating of formed parts to a temperature just below that of the recrystallization point of the metal to reduce stress corrosion. The rate of pitting corrosion was negligible. Corrosion rates were higher in industrial atmospheres (average less than 0.1 mil per year) and least in rural atmospheres (average less than 0.025 mil per year).

3. Galvanic-couple Corrosion Studies by Means of the Threaded Bolt and Wire Test. K. G. Compton and A. Mendizza. Atmospheric Corrosion of Non-Ferrous Metals, ASTM STP 175, American Society for Testing and Materials, 1956, pp. 116-125. (Fe56-7)

4. Report of Subcommittee on Atmospheric Corrosion. H. R. Copson. Atmospheric Corrosion of Non-Ferrous Metals, ASTM STP 175, American Society for Testing and Materials, 1956, pp. 3-19. (A156-4)
5. The Atmospheric Corrosion of Copper -- Result of 20-year tests. D. H. Thompson, A. W. Tracy, and J. R. Freeman, Jr. Atmospheric Corrosion of Non-Ferrous Metals, ASTM STP 175, American Society for Testing and Materials, 1956, p. 77-88.

Eleven brands of copper, in the form of sheet and wire, have been exposed for 20 years to four outdoor atmospheres in Connecticut. The effect of corrosion has been evaluated by loss in weight, loss in strength, and gain in electrical resistance. Some of the results have been examined by applying an analysis of variance. The mean corrosion rate was found to be on the order of 50×10^{-6} in per year. While the differences were of no practical significance, the purest coppers corroded least, and the arsenical coppers corroded most.

1955

1. Atmospheric Galvanic Couple Corrosion. K. G. Compton, A. Mendizza, and W. W. Bradley. Corrosion, v. 11, No. 9, 1955, pp. 35-44. (Fe55-1)
2. Oxidation of Copper in a Sulfur Dioxide Medium. L. T. Kleimenova. Tekh. Inform. Resul'tat. Nauch.-Issledovatel Rabot Leningrad. Lesotekh. Akad., No. 27, 1955, pp. 14-15.*

A method was developed for oxidation of metals in a sulfur dioxide medium. It was found that the rate of oxidation of copper in a sulfur dioxide medium is lower than in air and that it depends on the temperature and on the time of exposure.

1953

1. Effects of Aluminum and Manganese on Resistance Against Atmospheric Corrosion of Some Copper Alloys. G. P. Chatterjee. Indian Inst. Metals--Trans, v. 7, 1953, pp. 211-221.

The basic mechanism by which elements may impart resistance to alloys against atmospheric corrosion is discussed. Film growth is governed by the physical properties of film formed, diffusion of atoms or ions concerned, the temperature and environment.

2. The Behavior of Metallic Contacts at Low Voltages in Adverse Environments. A. Fairweather. Proc. I.E.E.E., v. 100, pt.1, 1953, pp. 174-182.

The surfaces of electrical contacts are usually contaminated by foreign layers. Such layers may consist of dust or grease, or of films produced by adsorption, tarnishing or corrosion. The applied voltage is regarded as "low" when it is too small to initiate conduction by any process analogous to breakdown. The problem in such circumstances is to obtain a metal-to-metal contact mechanically. An attempt is made, for the first time, to describe the behaviour of a closed contact subjected to corrosion, and the closure processes for a corroded contact, both with and without "wipe." The principles outlined provide some theoretical basis for design and testing techniques. Attention is also given to sliding contacts and, in particular, to the exposed intermittently-operating type: some new approaches to the problems involved are suggested, perhaps the most important being the development of a new technique for the continuous dry lubrication of sliding contacts in mechanical and electrical systems.

1952

1. Corrosion of Different Metals in Liquefied Sulfur Dioxide. J. Bollinger. Schweiz. Arch. angew. Wiss. u. Tech., v. 18, 1952, pp. 321-342. (Fe52-2)
2. Corrosion of Metals. U. R. Evans. Soc. Chem. Industry (Chem & Industry), No. 41, October 11, 1952, pp. 986-993. (Fe52-3)
3. Some Further Observations on the Painting of Aluminum Alloys. W. A. Edwards. Light Metals, v. 15, No. 167, 1952, pp. 61-63. (Fe52-5)

1951

1. Corrosion of Copper, Aluminum, and Magnesium and Their Alloys. M. Orman and E. Zalesinski. Hutnik, v. 18, 1951, pp. 96-101 (Polish). (Al51-1)
2. Corrosion Products of An Ancient Chinese Bronze. R. J. Gettens. J. Chem. Ed., v. 28, 1951, pp. 67-71.

The corrosion products on a Chou period bronze vessel containing about 21 percent tin and 4.5 percent lead occur in unusually well defined layered structures. From the interior the order is: unattacked metal core; residual dendritic metal structure in which a mixture of cupric and stannic oxides have replaced the eutectic part of the duplex cast structure; CuCl ; redeposited Cu ; Cu_2O and SnO_2 mixture; mixture of basic chloride and carbonate of copper. A series of chemical step reactions is proposed to explain the complex corrosion process.

3. Historic Church's Copper Roof Good After 213 Years. A. W. Tracey. Corrosion, v. 7, No. 11, 1951, pp. 373-375. (Fe51-3)

1950

1. A Few Extraordinary Cases of Brass Corrosion in an Atmosphere Containing Sulfurous Gases and Investigation of Such Cases. A. Domony. Banyasz. Kohasz. Lapok, v. 5, No. 83, 1950, pp. 421-425.

When brass samples containing 70, 63, or 58 percent copper were kept 2 hours in an atmosphere saturated with SO_2 and steam and then stored for week, the highest weight losses were observed in brasses with the highest copper contents. When similar brass samples were treated in an atmosphere containing SO_2 1 or H_2S 2 percent at 450° , or in an atmosphere containing SO_2 1 percent at 600° , the film formed on the surface of the brass contained Cu 70 and Zn 30, Cu 68 and Zn 32, Cu 10 and Zn 90, respectively, for brass containing Cu 70 and Zn 30; the film contained Cu 36 and Zn 64, Cu 36 and Zn 64, or Cu 2 and Zn 98, respectively, for brass containing Cu 63 and Zn 37; the film contained Cu 16 and Zn 85, Cu 30 and Zn 70, or Cu 0.0 and Zn 100, respectively, for brass containing Cu 68 and Zn 42 percent. When similar brass samples were kept at 20° in artificial sea water 3 weeks, the most severe corrosion occurred on the surface of brass containing 58 percent copper. The experiments show that the copper content of brass alone is not the most important factor in corrosion resistance. Corrosion seems to depend on the quality of the protective coating formed under corrosive conditions. Brass is generally more resistant owing to its homogeneous structure. Since, however, strongly adhesive ZnO films are not readily formed on the surface of α -brasses, they are sometimes corroded more easily than brasses of the $(\alpha + \beta)$ -structure. Two opposing processes take place in brass corrosion.

2. Atmospheric Corrosion of Metallic Materials in Closed Spaces. Schikorr. Feinmech. u. Prazis, v. 54, 1950, pp. 3-8. (A150-1)
3. Suppression of Corrosion of Copper and its Alloys. E. Q. Camp. U.S. Patent 2,522,430, September 12, 1950.

The corrosion of copper and copper alloys, when exposed to a fluid containing a compound from the group of NH_4OH and NH_3 , is eliminated by incorporating a sulfur-containing compound in the fluid. The sulfur compounds include H_2S , CS_2 , mercaptans, SO_2 and SO_3 , and their concentration may be varied over a wide range. The mercaptan concentration may be 0.002-6 mole percent of the compound if the fluid is a liquid and 0.02-2 mole percent of the compound if the fluid is a gaseous medium. A sample of Admiralty metal containing copper 69, zinc 29, and tin 1 percent and immersed for 48 hours in a 10 percent by weight solution of NH_4OH at room temperature corroded at a rate of 0.14 in. per year. When 0.8 percent of Bu mercaptan was added in an identical test, the corrosion rate was 0.0009 in. per year. In another test, the stressed metal failed in 3 hours as a result of stress-corrosion cracking in an atmosphere containing NH_3 . When 3 percent by weight of Bu mercaptan was added to the NH_4OH solution over which the stressed Admiralty metal was suspended, there was no evidence of failure after 194 hours of exposure.

1948

1. The Atmospheric Corrosion of Metals. G. Schikorr. Arch. Metallkunde, v. 2, 1948, pp. 223-230 (German). (Fe48-7)

1943

1. The Corrosion of Metals in Air. Jubilee Memorial Lecture. W. H. J. Vernon. Chemistry and Industry, August 1943, pp. 314-318. (Fe43-1)

1939

1. Effect of Sulfur Compounds in the Atmosphere on Various Materials. L. R. Burdick and J. F. Barkley. U.S. Bureau of Mines, I.C. 7064, April 1939, 9 pp. (Fe 39-1)

1937

1. The Atmospheric Corrosion of Metals. W. H. J. Vernon. Proc. Chemical Engineering Group (Soc. Chem. Ind.), v. 19, 1937, pp. 14-22. (Fe37-2)

1936

1. Corrosion Resistance of Metals and Alloys. R. J. McKay and R. Worthington. Reinhold Publishing Corporation, New York, N.Y., 1936. (Fe36-2)

1935

1. The Effect of Five Years' Atmospheric Exposure on the Breaking Load and the Electrical Resistance of Non-Ferrous Wires. J. C. Hudson. J. Inst. Metals, v. 56, 1935, pp. 91-102.

This paper gives the results of atmospheric corrosion tests in which various non-ferrous wires were exposed to an urban atmosphere for 5 years; the extent of corrosion was measured both by determination of the extent to which the breaking load of the wires had been decreased by exposure and by measurements of the increase in the electrical resistance of the wire. The results of the two series of tests are in reasonable agreement both with each other and with those of earlier tests. In general, the rate of corrosion observed was small, that of copper being, for instance, on the order of 0.0002 in. per annum; the rate was definitely higher for nickel, nickel-copper alloys with high nickel contents, zinc, and brass, the

breaking load of the last material being appreciably impaired by the effects of "copper redeposition." The most corroded material of all was galvanized iron wire, which failed rapidly when the zinc coating had corroded. Comparison of the present results with those of similar tests over shorter periods points to the conclusion that in many cases, such as those of copper and high-copper bearing alloys, the rate of corrosion decreases with time of exposure.

1930

1. The Effects of Two Years' Atmospheric Exposure on the Breaking Load of Hard-Drawn Non-Ferrous Wires. J. C. Hudson. J. Inst. Metals, v. 44, 1930, pp. 409-431.

Details are given of tests on a number of hard-drawn non-ferrous wires, in which determinations of the breaking load were made before and after exposure to the South Kensington atmosphere for two years. Owing to the fact that appreciable changes took place in the strength of the unexposed wires, it is not possible to arrange the materials in a definite order of merit as regards resistance to atmospheric corrosion. The losses in strength after two years' exposure were, however, very small, and the observations confirm the results of earlier work in showing that under straight forward conditions the majority of non-ferrous materials are very resistant to atmospheric corrosion. Brass is an exception to this statement, as its strength is adversely affected by the copper redeposition that accompanies atmospheric corrosion. A few remarks are made on the atmospheric corrosion of copper-nickel alloys.

1929

1. Atmospheric Corrosion of Metals-3rd Report to the Atmospheric Corrosion Research Committee. J. C. Hudson. Trans. Faraday Soc., v. 25, 1929, pp. 177-252. (A129-1)
2. Open-Air Corrosion of Copper. Chemical Study of the Surface Patina. W. H. J. Vernon and L. Whitby. J. Inst. Metals, Advance copy No. 511, 1929.

The green patina found on copper exposed to weathering conditions consists essentially of basic copper sulfate. Basic carbonate exists only in small quantities. Lead in the copper tends to cause the formation of black patinas. In most cases the patina passes through a black stage followed by subsequent changes to green. In marine atmospheres the patinas are usually composed of basic chlorides. Sulfur compounds are particularly effective in the developments of patinas. Impurities other than lead do not, as a rule, impart characteristic colors to the patina. The process of changing from black to green usually takes many years.

3. The Relative Corrodibilities of Ferrous and Non-Ferrous Metals and Alloys. Part II--The Results of Seven Years' Exposure to Air at Birmingham. J. N. Friend. J. Inst. Metals, v. 42, 1929, pp. 149-155. (Fe29-2)

1927

1. Second Experimental Report to the Atmospheric Corrosion Research Committee (British Non-Ferrous Metals Research Association). W. H. J. Vernon. Trans. Faraday Soc., v. 23, 1927, pp. 113-179.

The report is concerned with the behavior of typical metals and alloys on exposure to the atmosphere; it is divided into two parts, dealing respectively with "indoor" and "open-air" exposure tests, the former including associated laboratory experiments. It is shown that conclusions which hold good for a given set of conditions do not necessarily apply when those conditions are changed; this is exemplified by the influence of "impurities" in copper. Indoors, under conditions such that only tarnishing has to be considered, a given element exercises an effect which is either negligible, or in simple proportion to the amount of element present. Exposed to the open air however, the same element may exert an effect out of all proportion to its concentration. It would appear that protection against indoor tarnishing should be sought by methods other than modification of composition alone; promising results have been obtained in connection with the formation of protective surface films.

NICKEL ALLOYS

1982

1. Acid Rain: Impacts on the Natural and Human Environment. H. C. Martin. Materials Performance, v. 21, No. 1, January 1982, pp. 36-39. (Fe82-3)
2. Atmospheric Corrosion Testing of Electrodeposited Coatings in Tropical China. T. Biestek. Atmospheric Corrosion, edited by W.H. Ailor, Wiley, New York, N.Y., 1982, pp. 775-786.

Atmospheric corrosion testing of electroplated coatings were carried out in China in humid tropical (Canton), marine-tropical (Ju-Lin, Hainan island), and subtropical-industrial (Shanghai) atmospheres for four years. Zinc and cadmium (unchromated and chromated), tin, nickel, and three-layers copper-nickel-chromium coatings deposited on steel, tin, silver, passivated silver coatings on copper, and chromium coatings on brass were included in the test program. Durability of the above coatings was determined taking into account their thicknesses. Conclusions on the field of application of these coatings in tropical climate were drawn.

3. Colloid and Surface Phenomena in the Corrosion of Metals. E. Matijevic. Atmospheric Corrosion, edited by W.H. Ailor, Wiley, New York, N.Y., 1982, pp. 123-138. (Fe82-28)
4. Comments on the Corrosion Performance of Decorative Nickel-Iron Coatings. R. J. Clauss. Atmospheric Corrosion of Metals, edited by S. W. Dean, Jr., and E. C. Rhea, American Society for Testing and Materials, ASTM STP 767, 1982 pp. 214-221.

The durability of decorative nickel-iron coating in various types of exposure is discussed in detail. It has been determined that these coatings, as part of a specific multiple deposit system, perform acceptably for exterior automotive applications. It is necessary that a micro-discontinuous chromium be present in the composite coating to achieve optimum results, and it is desirable to use a copper underlayer to the nickel-iron electrodeposits. Corrosion test results are also reported which establish that static tests cannot be relied upon to predict actual mobile service performance.

5. Corrosion Performance of Decorative Electrodeposited Nickel and Nickel-Iron Alloy Coatings. G. A. DiBari, G. Hawks, and E. A. Baker. Comments on the Corrosion Performance of Decorative Nickel-Iron Coatings. R. J. Clauss. Atmospheric Corrosion of Metals, edited by S. W. Dean, Jr., and

E. C. Rhea, American Society for Testing and Materials, ASTM STP 767, 1982, pp. 186-213.

The corrosion performance of chromium-electroplated, decorative nickel and nickel-iron alloy electrodeposits has been studied in marine and industrial atmospheres and by means of copper-accelerated acetic acid-salt spray testing (CASS). Decorative nickel coatings, 15 and 30 μm thick, gave better overall corrosion performance than comparable decorative nickel-iron alloy coatings. Because of the rapid staining that occurs in marine and industrial atmospheres, nickel-iron alloy deposits are not suitable for decorative applications involving moderate and severe corrosion service. Decorative nickel-iron alloy deposits, 7.6 μm thick, appear suitable for mild corrosion service on the basis of CASS test results, but results were affected by iron content and type of electrodeposited chromium. The relatively good performance of thin alloy deposits accounts for established applications in mildly corrosive environments.

The performance of the decorative electrodeposited nickel coatings was influenced by the activity of bright nickel. Low-activity single-layer bright nickel (15 μm) performed better than high-activity bright nickel when used with microporous or microcracked chromium. High-activity double-layer nickel (30 μm) protected low-current-density areas of contoured steel panels better than low-activity double-layer nickel, either with microporous or microcracked chromium. Microporous chromium was more effective in this program; microcracked chromium was more effective in a previous study.

6. Economic Assessment of Pollution Related Corrosion Damage. F. H. Haynie. Atmospheric Corrosion, edited by W.H. Ailor, Wiley, New York, N.Y., 1982, pp. 3-18. (Fe82-33)
7. Electrochemical Behavior of Atmospheric Pollutants in Thin Liquid Layers Related to Atmospheric Corrosion. C. Fiaud. Atmospheric Corrosion, edited by W.H. Ailor, Wiley, New York, N.Y., 1982, pp. 161-166.

The influence of sulfur dioxide as gaseous atmospheric pollutant has been examined for its effect on the electrochemical behavior of metals under thin layers of moisture present on their surface. The concentration of sulfur dioxide was comprised between 4 and 100 ppm by volume. The investigated metals were platinum and nickel. Under these conditions, oxidation and reduction of sulfur dioxide were investigated, and adsorption of the molecule of the dissolved species was shown to play an important role in the extent of the electrochemical reactions occurring at the surfaces.

8. Electrotopotography - A New Tool for Corrosion Research. M. Ensanian. Extended Abstracts, International Symposium on Atmospheric Corrosion (October 5-10, 1980, Hollywood, Florida), Electrochemical Society, v. 80-2, 1980, pp. 480-482. (Fe82-36)
9. Evaluation of the Effects of Microclimate Differences on Corrosion. F. H. Haynie. Atmospheric Corrosion of Metals, edited by S. W. Dean, Jr., and E. C. Rhea, American Society for Testing and Materials, ASTM STP 767, STP 767, 1982, pp. 286-308. (Fe82-39).
10. Indoor Atmospheric Corrosion of Copper, Silver, Nickel, Cobalt and Iron. D. W. Rice, P. B. P. Phipps, P. J. Peterson and R. J. Cappell. Atmospheric Corrosion, edited by W.H. Ailor, Wiley, New York, N.Y., 1982, pp. 651-666. (Cu82-21)
11. Indoor Corrosion Testing. W. O. Freitag. Atmospheric Corrosion, edited by W.H. Ailor, Wiley, New York, N.Y., 1982, pp. 265-274. (Fe82-40)

1981

1. Acid Rain: Impacts on the Natural and Human Environment. H. C. Martin. Paper No. 114, Corrosion/81 (Toronto, Canada), National Association of Corrosion Engineers, Houston, TX, April 6-10, 1981, 7 pp. (Fe81-1)

1980

1. Corrosion of Metal in Wood Products. A. J. Baker. Durability of Building Materials and Components, ASTM STP 691, edited by P. J. Sereda and G. G. Litvan, American Society for Testing and Materials, 1980, pp. 981-993. (Fe80-7)
2. Critical Review of the Available Physicochemical Material Damage Functions of Air Pollution. M. Benarie. Report No. EUR-6643, Commission on the European Communities, 1980, 97 pp. (Fe80-81)
3. Indoor Corrosion of Metals. D. W. Rice, R. J. Cappell, W. Kinsolving, and J. J. Laskowski. J. of Electrochem. Soc., v. 127, No. 4, 1980, pp. 891-902. (Fe80-11)

1979

1. The Effect of Atmospheric Corrosion on the Reliability of Electronic Parts. B. Henzlik. Koroze Ochr. Mater., v. 5, 1974, pp. 90-91 (Czech). (Cu79-6)

1978

1. ASTM Atmospheric Corrosion Testing: 1906 to 1976. W. H. Ailor. Atmospheric Factors Affecting the Corrosion of Engineering Metals, ASTM STP 646, edited by S. K. Coburn, American Society for Testing and Materials, 1978, pp. 129-151. (Fe78-2)
2. Atmospheric Corrosion of Electroplated Zinc Alloy Die Castings. J. H. Payer and W. H. Safranek. Atmospheric Factors Affecting the Corrosion of Engineering Metals, ASTM STP 646, edited by S. K. Coburn, American Society for Testing and Materials, 1978, pp. 115-128. (Cu78-5)
3. Atmospheric Laboratory Bench. Yu. N. Mikhailovskii, V. A. San'ko, N. A. Sokolov, and P. N. Kudryavtsev. Zashch. Met., v. 14, No. 4, 1978, pp. 515-517 (Russian). (Fe78-7)

1977

1. Galvanic Corrosion In The Atmosphere. V. Kucera. Rapp.-Korrosionsinst. No. 16, 1977, 43 pp. (Swedish). (Fe77-9)

1976

1. Effects of Power Plant Emissions on Materials. J. E. Yocom and N. Grappone. Research Corporation of New England, Wethersfield, Connecticut, NTIS Report PB-257539, July 1976, 85 pp. (Fe76-6)
2. How Environmental Pollutants Diminish Contact Reliability. C. A. Russell. Insulation/Circuits, v. 22, No. 10, September 1976, pp. 43-46. (Cu76-5)
3. Protection Against Atmospheric Corrosion. K. Barton. Translated by J. R. Duncan, Wiley, New York, N.Y., 1976, 194 pp. (Fe76-14)

1975

1. Environmental Exposure System for Studying Air Pollution Damage to Materials. J. W. Spence, F. D. Stump, F. H. Haynie, and J. B. Upham. NTIS Report PB-240615/5ST, January 1975, 40 pp. (Fe75-11)
2. Sulfur Dioxide and Material Damage. D.G. Gillette. J. Air Pollution Control Assn., v. 25, No. 12, December 1975, pp. 1238-1243. (Fe75-17)
3. The Outdoor Corrosion Performance of Plated ABS Plastics. V. E. Carter. Trans. Inst. Metal Finishing, Spring/Conf., v. 53, No. 1, 1975, pp. 61-64. (Cu75-6)

1974

1. Air Pollution Effects on Catastrophic Failure of Metals. J. Gerhard and F. H. Haynie. Environmental Protection Agency, EPA-650/3-74-009, November 1974, 33 pp. (Fe74-2)
2. Seven-Year Exposure at Point Reyes, California. W. H. Ailor. Corrosion in Natural Environments, ASTM STP 558, American Society for Testing and Materials, 1974, pp. 75-81. (Al74-6)
3. The Economic Damages of Air Pollution. T. E. Waddell. NTIS Report PB-235701, 1974, 156 pp. (Fe74-21)
4. The Use of Weather and Climatological Data in Evaluating the Durability of Building Components and Materials. L. W. Masters and W. C. Wolfe. NTIS Report COM-74-50841/7, August 1974, 102 pp. (Fe74-25)

1973

1. Economic Effects of Air Pollution on Electrical Contacts. R. C. Robbins. Holm Seminar on Electrical Contact Phenomena, 19th Annual Proceedings, Illinois Inst. of Technology, Chicago, Ill., October 15-18, 1973, pp. 80-86. (Cu73-2)

1972

1. Atmospheric Corrosion Behavior of Stainless Steels and Nickel Alloys. T. E. Evans. Proc. 4th Int. Congr. Metal. Corros. (1969), National Association of Corrosion Engineers, Houston, TX, 1972, pp. 408-418. (Fe72-3)

1971

1. Atmospheric Corrosion of Metals. M. Arpaia. Atti Not. Assoc. Ital. Metall., v. 26, 1971, pp. 363-367 (Italian). (Fe71-5)
2. Technical-Economic Evaluation of Air-Pollution Corrosion Costs on Metals in the U.S. F. W. Fink, E. H. Buttner and W. K. Boyd. NTIS Report PB-198453, February 19, 1971, 160 pp. (Fe71-25)

1970

1. Systems Analysis of the Effects of Air Pollution on Materials. R. L. Salmon. NTIS Report PB-209192, January 15, 1970, 196 pp. (Fe70-13)

1969

1. Corrosion in the Atmosphere P. Atterby. NTIS Report N71-26259, November 1969, 9 pp. (Swedish). (Fe69-25)

1968

1. Atmospheric Corrosion Behavior of Some Nickel Alloys. D. Van Rooyen and H. R. Copson. Metal Corrosion in the Atmosphere, ASTM STP 435, American Society for Testing and Materials, 1968, pp. 175-186.

Nickel, nickel-copper, and nickel-chromium-iron alloys were included in an atmospheric corrosion test series in industrial, marine, and rural sites. Pit depths, losses in weight, and losses in mechanical properties were extremely small after a seven-year period of exposure. The nickel-iron-chromium materials had the lowest corrosion rates, about 0.01 milligrams per square decimeter per day (about 0.002 mils per year). The corrosion rates of the nickel-iron-chromium alloys appear to have decreased substantially with exposure time, while the nickel and nickel-copper alloy specimens follow approximately linear rates. Long time durability data have also been obtained for a number of nickel-copper-iron alloys. These were boldly exposed at Bayonne, N.J. for almost 40 years. Data led to the construction of isograms connecting compositions of equal durability on the nickel-iron-copper ternary diagram. Effects of exposure under shelter are also discussed.

2. Corrosion of Metals by Aqueous Solutions of the Atmospheric Pollutant Sulfurous Acid. W. McLeod and R. R. Rogers. Electrochem. Technol., v. 6, No. 7-8, July-August 1968, pp. 231-235. (Fe68-3)

3. High Pressure Electrical Contacts. J. King. Proc. 1968 Electrical Components Conference, May 8-10, 1968, pp. 454-458. (Fe68-9)
4. Increased Connector Contact Reliability. M. Ball, F. H. Hardie and E. J. Struckus, The Electronic Engineer, March 1968, pp. 82-85. (Al68-6)
5. Tarnishing and Contamination of Metals. W. E. Campbell and U. B. Thomas. Proc. Engineering Seminar on Electrical Contact Phenomena, Illinois Inst. Technology, Chicago, Ill., November 11-15, 1968, pp. 233-265. (Cu68-10)

1967

1. Surface Properties Key to Contact Selection. J. C. Chaston. Mat. Eng., v, 66, No. 8, 1967, pp. 76-77. (Cu67-4)

1966

1. Corrosion Behavior of Some Metallic Materials in Liquid Sulfur Dioxide. L. Rivola, T. Bazzan, M. Piro, and G. Bombara. Proc. 2nd Intern. Congr. Metal. Corrosion, New York, (1963), National Association of Corrosion Engineers, Houston, TX, 1966, pp. 418-423. (Fe66-6)
2. Tarnish Films on Electric Contact Materials. R. V. Chiarenzelli. Proc. Third Intern. Research Symposium on Electrical Contact Phenomena, June 6-10, 1966, pp. 85-93. (Cu66-8)

1965

1. Significance of Corrosion Testing Process with Special Consideration of the SO₂ Test According to DIN 50018. W. Kesternich. Werkst. Korrosion, v. 16, 1965, pp. 193-201 (German). (Fe65-15)
2. The Significance of Sulfur Dioxide in the Atmospheric Corrosion of Metals. G. Schikorr. Korrosion, No. 17, 1965, pp. 27-34 (German). (Fe65-20)

1964

1. Atmospheric Corrosion of Bright Nickel and Polished Dead Nickel Coatings. G. Schikorr. Metall, v. 18, 1964, pp. 594-596.

Tests were conducted both in the laboratory and in the atmosphere in the Stuttgart region. In the atmosphere, polished bright nickel specimens showed about 50 percent greater attack than polished dead nickel samples. This difference is attributed to the fact that bright nickel absorbs more SO_2 from the air and is, therefore, more reactive than polished dead nickel. Bright nickel also shows greater reactivity in laboratory tests.

2. Investigation of Atmospheric Corrosion Behavior of Selected Nickel Alloys.
H. R. Copson and E. A. Tice. Werkst. Korros., v. 15, No. 8, August 1964, pp. 642-652 (German). (Fe64-3)
3. The Influence of Sulphur Dioxide on the Atmospheric Corrosion of Metals.
G. Schikorr. Werkst. Korros., v. 15, No. 5, 1964, pp. 457-463.
(Fe64-4)

1961

1. Atmospheric Corrosion. U. R. Evans. Chapt. 8 in The Corrosion and Oxidation of Metals, Edward Arnold, 1961, pp. 481-535. (Fe61-2)
2. Corrosion In Buildings. P. J. Sereda. Canadian Building Digest. Report No. CBD-20, August 1961, 4 pp. (Fe61-5)
3. Equivalence of the Atmospheric Corrosion of Zinc and Nickel to That of Sulfur Dioxide Absorbed From the Air. G. Schikorr. Metall, v. 15, 1961, pp. 981-987.

After a 1-year exposure to atmospheric corrosion at Stuttgart, the metal surfaces at most absorbed only one-third to one-half the amount of SO_2 absorbed by alkaline surfaces of the same magnitude, consisting of K_2CO_3 -impregnated filter paper. Rain has little effect on the amount of corrosion. In cold months the corrosion on zinc, nickel is about equal. In hot months, during which corrosion is considerably less, zinc is somewhat more severely attacked than nickel. Zinc, in the presence of 70 to 80 percent humidity, takes up more SO_2 from the air than nickel, and corrodes more severely than nickel owing to the formation of basic salts. This condition would prevail to a greater extent during the warm months.

1959

1. Corrosion of Metals in Synthetic Atmospheres Containing Sulfur Dioxide.
B. Sanyal and D. V. Bhadwar. J. Sci. Industr. Res., v. 18A, February 1959, pp. 69-74. (Fe59-3)

2. Design and Interpretation of Atmospheric Corrosion Tests. H. R. Copson. Corrosion, v. 15, No. 10, October 1959, pp. 533t-541t. (Fe59-4)
3. Mechanism by Which Nonferrous Metals Corrode in the Atmosphere. M. Aziz and H. P. Goddard. Corrosion, v. 15, No. 10, 1959, pp. 529t-533t. (A159-3)

1957

1. The Effects of Air Pollution on Buildings and Metalwork. R. J. Schaffer. Air Pollution, edited by M. W. Thring, Butterworth Scientific, London, 1957, pp. 58-71. (Fe57-5)

1956

1. Atmospheric Corrosion Behavior of Some Nickel Alloys. H. R. Copson. Atmospheric Corrosion of Nonferrous Metals, ASTM STP 175, American Society for Testing and Materials, 1956, pp. 141-158. (Fe56-2)
2. Report of Subcommittee on Atmospheric Corrosion. H. R. Copson. Atmospheric Corrosion of Non-Ferrous Metals, ASTM STP 175, American Society of Testing and Materials, 1956, pp. 3-19. (A156-4)

1955

1. Atmospheric Galvanic Couple Corrosion. K. G. Compton, A. Mendizza, and W. W. Bradley. Corrosion, v. 11, No. 9, 1955, pp. 35-44. (Fe55-1)

1953

1. The Behavior of Metallic Contacts at Low Voltages in Adverse Environments. A. Fairweather. Proc. I.E.E.E., v. 100, pt. 1, 1953, pp. 174-182. (Cu53-2)

1952

1. Corrosion of Different Metals in Liquefied Sulfur Dioxide. J. Bollinger. Schweiz. Arch. angew. Wiss. u. Tech., v. 18, 1952, pp. 321-342. (Fe52-2)

1948

1. The Atmospheric Corrosion of Metals. G. Schikorr. Arch. Metallkunde, v. 2, 1948, pp. 223-230 (German). (Fe48-7)

1939

1. Effect of Sulfur Compounds in the Atmosphere on Various Materials. L. R. Burdick and J. F. Barkley. U.S. Bureau of Mines I.C. 7064, April 1939, 9 pp. (Fe39-1)

1937

1. The Atmospheric Corrosion of Metals. W. H. J. Vernon. Proceedings Chemical Engineering Group (Soc. Chem. Ind.), v. 19, 1937, pp. 14-22. (Fe37-2)

1936

1. Corrosion Resistance of Metals and Alloys. R. J. McKay and R. Worthington. Reinhold Publishing Corporation, New York, N.Y., 1936. (Fe36-2)

1935

1. The Effect of Five Years' Atmospheric Exposure on the Breaking Load and the Electrical Resistance of Non-Ferrous Wires. J. C. Hudson. J. Inst. Metals, v. 56, 1935, pp. 91-102. (Cu35-1)

1930

1. The Effects of Two Years' Atmospheric Exposure on the Breaking Load of Hard-Drawn Non-Ferrous Wires. J. C. Hudson. J. Inst. Metals, v. 44, 1930, pp. 409-431. (Cu30-1)

1929

1. Atmospheric Corrosion of Metals--3rd Report to The Atmospheric Corrosion Research Committee. J. C. Hudson. Trans. Faraday Soc., v. 25, 1929, pp. 177-252. (A129-1)

2. The Relative Corrodibilities of Ferrous and Non-Ferrous Metals and Alloys.
Part II--The Results of Seven Years' Exposure to Air at Birmingham.
J. N. Friend. J. Inst. Metals, v. 42, 1929, pp. 149-155. (Fe29-2)

ZINC AND GALVANIZED STEEL

1982

1. Acid Rain: Impacts on the Natural and Human Environment. H. C. Martin. Materials Performance, v. 21, No. 1, January 1982, pp. 36-39. (Fe82-3)
2. Atmospheric Corrosion of Galvanized Steel. R. A. Legault. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 607-614.

It has previously been demonstrated that the natural atmospheric corrosion behavior of galvanized steel can be accurately described by equations of a simple form. Such equations are used to demonstrate that differences in the behavior of galvanized steel can be easily and accurately assessed. Examples are given of differences in behavior which result from variations in coating composition as well as from variations in exposure environment. Comparisons are also shown of the behavior of galvanized steel to that of other materials.

3. Atmospheric Corrosion of Metals Under Moving Conditions. J. D. Talati and B. M. Patel. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 695-704. (Fe82-10)
4. Atmospheric Corrosion of Zinc and its Alloys. S. R. Dunbar, and W. Showak. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 529-552.

Zinc corrosion rates are influenced by their environment. Alloy composition has little influence on corrosion rates but may control surface texture. Corrosion rates are lowest in rural environments. The corrosion products formed are basic and relatively insoluble which form a protective film and reduce the corrosion rate. Corrosion rates are highest in industrial atmospheres where moisture is acidic and corrosion products are soluble, allowing corrosion to proceed at a linear rate. In marine environments, corrosion rates depend on the amount of contact with salt spray. Atmospheric conditions during the first weeks of exposure may influence the corrosion rate of zinc during the entire exposure period. Zinc weight loss determinations appear to be the most suitable method for determining corrosion rates. The value of tension tests as a means of determining corrosion rates has been explored. To be useful, a means of separately evaluating the aging effects is needed.

5. Atmospheric Corrosion Test Results for Metallic-Coated Steel Panels Exposed in 1960. D. E. Tonini. Atmospheric Corrosion of Metals, edited by S. W. Dean, Jr., and E. C. Rhea, American Society for Testing and Materials, ASTM STP 767, 1982, pp. 163-185. (A182-9)

6. Atmospheric Corrosion Testing by Electrolytic Cells in Norway and Sweden. S. Haagenrud, V. Kucera, and J. Gullman. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 669-694. (Fe82-14)
7. Atmospheric Corrosion Testing in Australasia. J. F. Moresby, F. M. Reeves and D. J. Spedding. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 745-754. (Fe82-15)
8. Atmospheric Corrosion Testing in Brazil. A. C. Dutra and R. Vianna. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 755-774. (Fe82-16)
9. Atmospheric Corrosion Testing in Finland. T. Hakkarainen and S. Ylasaari. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 787-796. (Fe82-17)
10. Atmospheric Corrosion Testing In The Federal Republic of Germany. G. Oelsner. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 797-806. (Fe82-18)
11. Atmospheric Corrosion Testing in Norway. L. Atteraas and S. Haagenrud. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 873-892. (Fe82-20)
12. Atmospheric Corrosion Testing in Southern Africa. B. G. Callaghan. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 893-912. (Fe82-21)
13. Atmospheric Corrosion Testing in Spain. S. Feliu and M. Morcillo. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 913-922. (Fe82-22)
14. Atmospheric Corrosion Tests in the USSR. Yu. N. Mikhailovskii and P. V. Strekalov. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 923-942. (Fe82-23)
15. Atmospheric Corrosion Testing of Electrodeposited Coatings in Tropical China. T. Biestek. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 775-786. (Ni82-1)
16. Atmospheric Corrosion Testing of Electrodeposited Zinc and Cadmium Coatings. T. Biestek. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 631-644.

In light of examinations being carried out in various countries, the results of the more than ten years of atmospheric corrosion testing of electroplated zinc and cadmium coatings, 1-30 μm thick, on steel are discussed. Examinations were carried out in following natural atmospheres: industrial, urban-industrial, urban-coastal, and rural. Chromate layers on zinc coatings were tested. The results obtained were the basis to compare the protective properties of zinc and cadmium coatings, to determine the corrosion rate and durability of zinc coatings and to establish the relation and correlation between the results of laboratory (accelerated) and natural atmospheric testing.

17. Atmospheric and Weather Factors in Corrosion Testing. H. Guttman. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 51-68. (Fe82-25)
18. Calibration of Atmospheric Corrosion Test Sites. E. A. Baker and T. S. Lee. Atmospheric Corrosion of Metals, edited by S. W. Dean, Jr., and E. C. Rhea, American Society for Testing and Materials, ASTM STP 767, 1982, pp. 250-266. (Fe82-27)
19. Cobalt and Nickel Cations as Corrosion Inhibitors for Galvanized Steel. H. Leidheiser, Jr., and I. Suzuki. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 615-630.

Gravimetric measurements on galvanized steel and cathodic polarization curves indicate that corrosion of zinc in 3% NaCl is inhibited by a low concentration of cobalt ions in solution or by simple predipping the zinc in 0.05 or 0.1M solutions of CoCl_2 . Corrosion inhibition is also obtained when zinc is predipped in a nickel acetate solution and nickel ions are present in the NaCl solution. The corrosion inhibition is attributed to electron traps (cobalt or nickel atoms) in the zinc oxide on the surface of zinc which lead to inhibition of the cathodic reaction, $\text{H}_2\text{O} + 1/2 \text{O}_2 + 2\text{e}^- = 2\text{OH}^-$. When the concentration of elemental cobalt or nickel in or on the oxide becomes too great, the cathodic reaction, $2\text{H}^+ + 2\text{e}^- = \text{H}_2$, is catalyzed and corrosion activation occurs.

20. Economic Assessment of Pollution Related Corrosion Damage. F. H. Haynie. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 3-18. (Fe82-33)
21. Effect of 1 Percent Copper Addition on Atmospheric Corrosion of Rolled Zinc After 20 Years' Exposure. W. Showak and S. R. Dunbar. Atmospheric Corrosion of Metals, edited by S. W. Dean, Jr., and E. C. Rhea, American Society for Testing and Materials, ASTM STP 767, 1982, pp. 135-162.

The atmospheric corrosion characteristics of a commercial rolled zinc alloy containing 1 percent copper and an unalloyed grade have been evaluated after 20 years' exposure under ASTM Committee B-3 (now G

01.04.04) 1957 test program on atmospheric corrosion of non-ferrous metals. Corrosion damage was assessed by measurement of loss in weight, loss in mechanical properties, and depth of pitting. The 20-year corrosion rates are analyzed with respect to previous 2- and 7-year results. Comparisons are also made with the behavior of three unalloyed grades of rolled zinc investigated in the 20-year 1931 program by Committee B-3 using weight loss and tension test methods.

The weight loss method appears to be the most reliable way of determining the corrosion rates of zinc. Corrosion rates found for zinc in the 1931 and 1957 test programs are in good agreement. The corrosion rate of zinc is not significantly affected by variations in compositions investigated.

Local galvanic action is probably responsible for the pitting which occurs in the copper-containing zinc alloy. Pitting is most severe in the marine atmosphere in direct contact with salt spray. The pit-depth/total-penetration ratio tends to decrease with increasing total penetration. The net change in tensile strength after 20 years' exposure at all four test sites is equal to or less than that expected due to weight loss. Tensile elongation is found to be more sensitive to corrosion effects than tensile strength, although both alloys still possess considerable ductility after 20 years.

A better way of compensating for aging in zinc is needed if tension test results are to be useful in evaluating corrosion damage.

22. Electrotography - A New Tool for Corrosion Research. M. Ensanian. Extended Abstracts, International Symposium on Atmospheric Corrosion (October 5-10, 1980, Hollywood, Florida), Electrochemical Society, v. 80-2, 1980, pp. 480-482. (Fe82-36)
23. Evaluation of the Effects of Microclimate Differences on Corrosion. F. H. Haynie. Atmospheric Corrosion of Metals, edited by S. W. Dean, Jr., and E. C. Rhea, American Society for Testing and Materials, ASTM STP 767, 1982, pp. 286-308. (Fe82-39)
24. Ion Chromatographic Analysis of Contaminants on Zinc and Aluminum Surfaces Exposed to a Range of Urban Indoor Environments. G. B. Munier, L. A. Psota-Kelty, and J. D. Sinclair. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 275-284. (A182-23)
25. Progress in Atmospheric Corrosion Testing. D. Knotkova, K. Barton and M. Cerny. Extended Abstracts, International Symposium on Atmospheric Corrosion (October 5-10, 1980, Hollywood, Florida), Electrochemical Society, v. 80-2, 1980, pp. 526-528. (Fe82-44)
26. Resistance of Galvanized, Aluminum-Coated, and 55% Al-Zn-Coated Steels to Atmospheric Corrosion Involving Standing Water. L. Allegra, N. S. Berke, and H. E. Townsend. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 595-606. (A182-27)

27. Service Evaluation of Zinc Thermal Spraying Systems. K. Altorfer. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 645-650.

Rising costs suggest that longer lasting corrosion-prevention systems be developed. Reduction in consumption of zinc by the automotive industry makes it economically attractive for other applications. Zinc metallizing, providing up to 40 year life in Europe, is in its infancy in the United States. Texasgulf is now testing zinc metallizing for its railroad fleet, new construction and maintenance. Analysis indicates a favorable cost picture for zinc metallizing vs. conventional paint over a 20-40 year life span.

28. The Interplay of Weather, Climate and the Durability of Materials. P. W. Brown and L. W. Masters. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 31-50. (Fe82-43)

1981

1. Acid Rain: Impacts on the Natural and Human Environment. H. C. Martin. Paper No. 114, Corrosion/81 (Toronto, Canada), National Association of Corrosion Engineers, Houston, TX, April 6-10, 1981, 7 pp. (Fe81-1)
2. Corrosion Resistance of Zinc Coatings Produced in Modern Electrolytic Baths. T. Johnsson. Rapp.-Korrosionsinst. (Stockholm), No. 3, 1981, 27 pp. (Swedish).*

Zn electrodeposits from acid chloride, alkali noncyanide, low-cyanide, neutral, and conventional high-cyanide baths were field-tested for 4 yr, in rural, urban, and marine atms. Two accelerated tests were also carried out. No significant differences in anticorrosion efficiency were observed. Some differences were found in the bendability and ductility of the plates.

3. Determination of the Corrosivity of Atmospheres with Electrochemical Techniques. F. Mansfeld. Extended Abstracts, Fall Meeting, Electrochemical Society, Denver, CO., v. 81-2, October 11-16, 1981, pp. 444-445. (Fe81-7)
4. Evaluation of Electrochemical Techniques for Monitoring of Atmospheric Corrosion Phenomena. F. Mansfeld. Electrochemical Corrosion Testing, ASTM STP 727, edited by F. Mansfeld and U. Bertocci, American Society for Testing and Materials, 1981, pp. 215-237. (Fe81-9)
5. Practical Experience with an Electrochemical Technique for Atmospheric Corrosion Monitoring. V. Kucera and J. Gullman. Electrochemical Corrosion Testing, ASTM STP 727, edited by F. Mansfeld and U. Bertocci, American Society for Testing and Materials, 1981, pp. 238-255. (Fe81-12)

1980

1. A Model of Atmospheric Corrosion of Metals Allowing for Meteorological and Aerochemical Characteristics. Y. N. Mikhailovskii, P. V. Strekalov, and V. V. Agafonov. Protection of Metals, v. 16, No.4, 1980, pp. 308-323. (Fe80-1)
2. A Review of Air Pollutant Damage to Materials. J. E. Yocum and A. R. Stankunas. Draft Report to Environmental Criteria and Assessment Office, Office of Research and Development, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, December 1980, 92 pp. (Fe80-2)
3. Corrosion of Metal in Wood Products. A. J. Baker. Durability of Building Materials and Components, ASTM STP 691, edited by P. J. Sereda and G. G. Litvan, American Society for Testing and Materials, 1980, pp. 981-993. (Fe80-7)
4. Critical Review of the Available Physicochemical Material Damage Functions of Air Pollution. M. Benarie. Report No. EUR-6643, Commission on the European Communities, 1980, 97 pp. (Fe80-8)
5. Examination of Durability Test Methods for Building Materials Based on Performance Evaluation. T. Nireki. Durability of Building Materials and Components, ASTM STP 691, edited by P. J. Sereda and G. G. Litvan, American Society for Testing and Materials, 1980, pp. 119-130.

One of the vital approaches to quantifying the performance of materials over time is to use performance concept. This paper provides a methodology for evaluating durability test methods for building materials, components, and elements according to performance evaluation criteria. It discusses various sources of data (field survey, outdoor exposure and accelerated aging test) and includes 5-year application program for durability assessment of industrialized dwellings.

6. Laboratory Studies of Atmospheric Corrosion--I. Weight Loss and Electrochemical Measurements. F. Mansfeld and S. Tsai. Corrosion Science, v. 20, 1980, pp. 853-872. (Fe80-13)
7. Mechanism of SO₂ and H₂SO₄ Aerosol Zinc Corrosion. A. B. Harker, F. Mansfeld, D. R. Strauss, and D. D. Landis. Report to the Environmental Protection Agency, Contract No. 68-02-2944, January 1980.

A twelve-month experimental study has been conducted to establish the physical variables controlling the SO_2 (gas) and H_2SO_4 (aerosol) induced corrosion of zinc. The study was carried out using a 6.6 meter aerosol flow reactor in which relative humidity, temperature, air flow velocity, flow turbulence, aerosol size range, and pollutant concentration were controlled. Corrosion measurements were made through the use of an atmospheric corrosion monitor previously developed in this laboratory. The results of the study showed that the principal factors controlling pollutant induced corrosion are relative humidity (time of surface wetness), the rate of pollutant flux to the surface, and the chemical form of the pollutant. Temperature was not observed to be a controlling factor within the experimental range (12 to 20C). Sulfur dioxide was observed to induce a higher corrosion rate in the zinc than H_2SO_4 on a molecule for molecule basis. Flow dynamic measurements provided bulk and size detailed deposition velocities for two different accumulation mode H_2SO_4 aerosol size distributions as a function of frictional velocity, and a deposition velocity for SO_2 gas. The overall results indicate that under most ambient conditions SO_2 induced corrosion damage will dominate over H_2SO_4 effects. This study demonstrated the capability of the experimental technique to observe the physical and chemical processes controlling pollutant induced corrosion and offers a means of quantitatively describing these effects through further investigation.

8. Metals in America's Historic Buildings. M. Gayle, D. W. Look, and J. G. Waite. U.S. Department of the Interior, Heritage Conservation and Recreation Service, Washington, D.C., 1980, 170 pp. (Fe80-14)
9. Regional Air Pollution Study: Effects of Airborne Sulfur Pollutants on Materials. F. Mansfeld. NTIS Report PB81-126351, January 1980, 163 pp. (Fe80-18)
10. Theoretical Air Pollution and Climate Effects on Materials Confirmed by Zinc Corrosion Data. F. H. Haynie. Durability of Building Materials and Components, edited by P. J. Sereda and G. G. Litvan, American Society for Testing and Materials, ASTM STP 691, 1980 pp. 157-175.

Observed effects of pollution level, relative humidity, temperature, wind velocity, and surface geometry are explained using diffusion theory and thermodynamics. Many materials readily react with pollutants, thus, the rate controlling step is the flux of pollutants to the surface. In such cases, dose-response damage coefficients can be calculated from turbulent diffusion theory. Electrochemical corrosion of metals occurs when the surfaces are wet. A surface will become wet when the relative humidity adjacent to the surface exceeds a value in equilibrium with a saturated solution of a corrosion product or contaminant on the surface. Based on these considerations, the consistency of predictions with observed effects suggests that air pollution damage functions can be calculated for a variety of material surfaces for which data are not available.

1979

1. Atmospheric Corrosion of Metallic Systems. II. Analysis of the Corrosiveness of a Medium at Atmospheric Testing Stations of Comecon Countries Based on the Results of Five Year Tests on Steel, Zinc, Copper, and Aluminum. K. Barton, D. Knotkova, P. V. Strekalov, V. Kemkhadze, V. Kozhukharov, and A. Szobor. Zashch. Met., v. 15, No. 4, 1979, pp. 408-415 (Russian). (Fe79-1)
2. Atmospheric Corrosion Resistance of 55% Aluminum-Zinc Coated Sheet Steel: 13 Year Test Results. H. E. Townsend and J. C. Zoccola. Mater. Perform., v. 18, No. 10, 1979, pp. 13-20. (Al79-2)
3. Electrochemical Studies of Atmospheric Corrosion. F. B. Mansfeld. NTIS Report AD-A063922, January 1979, 135 pp. (Fe79-6)
4. Results of 30 Months Atmospheric Corrosion Testing in St. Louis, MO, U.S.A. F. Mansfeld. Reliability of Materials for Solar Energy Workshop Proceedings, CONF-781228, v. 2, pt. 1, October 1979, pp. 627-657. (Fe79-7)
5. Statistical Assessment of the Effect of Fluctuations in the Atmospheric Concentration of Sulfur Dioxide on the Corrosion Rate of Metals. Yu. N. Mikhailovskii and A. P. San'ko. Zashch. Met., v. 15, No. 4, 1979, pp. 432-437 (Russian). (Fe79-8)

1978

1. ASTM Atmospheric Corrosion Testing: 1906 to 1976. W. H. Ailor. Atmospheric Factors Affecting the Corrosion of Engineering Metals, ASTM STP 646, edited by S. K. Coburn, American Society for Testing and Materials, 1978, pp. 129-151. (Fe78-2)
2. Atmospheric Corrosion Behavior of Aluminum-Zinc Alloy Coated Steel. J. C. Zoccola, H. E. Townsend, A. R. Borzillo, and J. B. Horton. Atmospheric Factors Affecting the Corrosion of Engineering Metals, ASTM STP 646, edited by S. K. Coburn, American Society for Testing and Materials, 1978, pp. 165-184. (Al78-2)
3. Atmospheric Corrosion of Electroplated Zinc Alloy Die Castings. J. H. Payer and W. H. Safranek. Atmospheric Factors Affecting the Corrosion of Engineering Metals, ASTM STP 646, edited by S. K. Coburn, American Society for Testing and Materials, 1978, pp. 115-128. (Cu78-5)

4. Atmospheric Laboratory Bench. Yu. N. Mikhailovskii, V. A. San'ko, N. A. Sokolov, and P. N. Kudryavtsev. *Zashch. Met.*, v. 14, No. 4, 1978, pp. 515-517 (Russian). (Fe78-7)
5. Behavior of Zinc-Coated Steel in Highway Environments. G. German. *Atmospheric Factors Affecting the Corrosion of Engineering Metals*, ASTM STP 646, edited by S. K. Coburn, American Society for Testing and Materials, 1978, pp. 74-82.

Results of 3 to 7 year exposure periods for galvanized steel specimens in Ontario and Quebec highway environments are reported. Continuous hot-dip, batch hot-dip, and electrogalvanized materials were used. Results indicated that a coating life of five years per mil of coating can be expected in urban environments, and 10 to 20 percent longer protection in rural environments. The method of zinc application appeared to have no significant influence.
6. Corrosion Investigations at Panama Canal Zone. M. A. Pelensky, J. J. Jaworski, and A. Gallaccio. *Atmospheric Factors Affecting the Corrosion of Engineering Metals*, ASTM STP 646, edited by S. K. Coburn, American Society for Testing and Materials, 1978, pp. 58-73. (Fe78-9)
7. Corrosion Prevention with Thermal-Sprayed Zinc and Aluminum Coatings. F. N. Longo and G. J. Durmann. *Atmospheric Factors Affecting the Corrosion of Engineering Metals*, ASTM STP 646, edited by S. K. Coburn, American Society for Testing and Materials, 1978, pp. 97-114. (Al78-4)
8. Deteriorative Effect of Sulfur Pollution on Materials. J. O. Nriagu. Chapt. 1 in *Sulfur in the Environment, Part II: Ecological Impacts*, edited by J. O. Nriagu, Wiley, New York, N.Y., 1978, pp. 1-59 (Fe78-11)
9. Effects of Air Pollutants on Weathering Steel and Galvanized Steel: A Chamber Study. F. H. Haynie, J. W. Spence and J. B. Upham. *Atmospheric Factors Affecting the Corrosion of Engineering Materials*, ASTM STP 646, edited by S. K. Coburn, American Society for Testing and Materials, 1978, pp. 30-47. (Fe78-12)
10. Kinetics of the Atmospheric Corrosion of Galvanized Steel. R. A. Legault and V. P. Pearson. *Atmospheric Factors Affecting the Corrosion of Engineering Metals*, ASTM STP 646, edited by S. K. Coburn, American Society for Testing and Materials, 1978, pp. 83-96.

Atmospheric corrosion behavior was evaluated separately on skyward and groundward surfaces of galvanized steel test panels exposed in both industrial and marine environments. The behavior in every case can be accurately described by the same general kinetic relationship, $\Delta W = Kt^N$, where the empirically determined coefficients, K and N, can be used to

separate the tendency for a corrosion product to form from the effect of that corrosion product on the subsequent reaction. The specific kinetic equations which apply in each case can be used to reliably predict long-term atmospheric corrosion behavior.

11. The Corrosion and Protection of Metals in the Building and Construction Industries. B. G. Callaghan. J. Oil Color Chemists Assoc., v. 61, No. 11, November 1978, pp. 411-418. (Fe78-17)

1977

1. Corrosion Behavior of Galvanized Sheet in Relation to Variation in Coating Thickness. C. E. Bird. Materials Prot. Perform., v. 16, No. 4, 1977, pp. 14-16.

Appearance of 5 percent red rust on common galvanized steel at times shorter than the theoretical life of an equivalent thickness of zinc was the result of coating-thickness variations. The average thickness of 20 g Zn/yd² was 20.3 μ m. On 5 percent of the surface, the coating thickness was less than 11.0 μ m. Tests at 7 of the sites having widely varying aggressiveness indicated there was no significant difference in the atmospheric corrosion rate of galvanized steel compared to that of zinc. Thickness variations probably increased with increasing coating thickness.

2. Corrosion Behavior of Sheet Zinc Alloys in the Atmosphere and in the Steam Test. E. Pelzel. Metall., v. 31, No. 9, September 1977, pp. 978-981 (German).

Considering the present degree of air pollution, the corrosion mechanism and corrosion resistance of zinc in rural, marine, and industrial atmospheres is summarized on the basis of the literature and new experimental data.

3. Estimation of Pollutants Concentration in Atmosphere by Measuring Corrosion Rates of Several Metals. II. Correlation Between Reflectances of Exposed Metals and Deterioration of Exposed Rubber. G. Takao, and M. Masakasu. Taiki Osen Kenkyu, v. 11, No. 6, 1977, pp. 452-455 (Japanese). (Cu77-2)
4. Galvanic Corrosion In the Atmosphere. V. Kucera. Rapp.-Korrosionsinst., No. 16, 1977, 43 pp. (Swedish). (Fe77-9)

1976

1. Air Pollution Damage Functions. A. Hershaft. Environmental Science and Technology, v. 10, No. 10, October 1976, pp. 992-995.

In spite of the large amount of effort that has been devoted to development of air pollution damage functions for, among other effects, materials damage, and compilation of air quality trends, this new and promising area of investigation has been barely breached. The additional effort needed has been outlined in the introductory discussion. Illustrative examples include the effect of SO_2 on the corrosion of zinc. Damage functions will provide public officials with an effective tool for efficiently allocating limited resources among the many conflicting demands for pollution control and other aspects of the social welfare.

2. Effects of Gaseous Pollutants on Materials: A Chamber Study.
F. H. Haynie, J. W. Spence, and J. B. Upham. NTIS Report PB-251580, 1976, 98 pp. (Fe76-5)
3. Effects of Power Plant Emissions on Materials. J. E. Yocom and N. Grappone. Research Corporation of New England, Wethersfield, Connecticut, NTIS Report PB-257539, July 1976, 85 pp. (Fe76-6)
4. Electrochemical Monitoring of Atmospheric Corrosion Phenomena.
F. Mansfeld and J. V. Kenkel. Corrosion Science, v. 16, No. 3, 1976, pp. 111-122. (Fe76-9)
5. Initial Stages of Atmospheric Corrosion of Metals in Humid Air Above and Below the Freezing Point. Y. N. Mikhailovskii, P. V. Strekalov, and T. S. Balandina. Zashch. Met., v. 12, No. 5, 1976, pp. 513-518 (Russian).

The adsorption kinetics of water (gases) on vapor-deposited Ag. Cd. and Zn films on quartz was investigated at -20 to 20°C . A reaction model was proposed.

6. Physical and Economic Damage Functions for Air Pollutants by Receptor.
B. Liu and E. S. Yu. Report No. EPA 600/5-76-011, U.S. Environmental Protection Agency, September 1976, 172 pp. (Fe 76-13)
7. Pitting of Galvanized Steel in Controlled Clean Air Environments.
J. W. Spence and F. H. Haynie. Galvanic and Pitting Corrosion--Field and Laboratory Studies, ASTM STP 576, 1976, pp. 132-146.

Specimens of galvanized steel sheet were exposed to polluted and clean air in controlled environmental chambers having the capability to

simulate diurnal conditions. Corrosion of the zinc films was essentially a linear function of time for each exposure condition. The range of weight losses for the polluted and clean air environments were approximately the same. However, uniform corrosion of the zinc occurred in the polluted exposures whereas pitting corrosion of the zinc was observed in the clean air exposures.

Scanning electron microscopy microprobe analysis of the galvanized zinc surface was used to study the mechanism of initiation and propagation of pitting corrosion. Corrosion products were observed to localize and form a barrier that could accentuate an acidic condition within the pit. Pitting corrosion is thus accelerated by the difference in pH within and outside the pit. During the pollutant exposures, however, pitting corrosion is prevented because the drastic difference in pH within and outside the pit did not occur.

8. Protecting Electronics From Atmospheric Corrosion. D. V. Couden. Materials Engineering, May 1976, pp. 22-25. (Cu76-7)
9. Protection Against Atmospheric Corrosion. K. Barton. Translated by J. R. Duncan, Wiley, New York, N.Y., 1976, 194 pp. (Fe76-14)

1975

1. Atmospheric Corrosion Investigation of Aluminum-Coated, Zinc-Coated, and Copper-Bearing Steel Wire and Wire Products. V. I. Kelley. ASTM STP 585, American Society for Testing and Materials, 1975, 89 pp. (A175-1)
2. Corrosion of Coated Metals. 6. Atmospheric Exposure. J. B. Mohler. Met. Finish., v. 73, No. 9, 1975, pp. 48-51. (Fe75-5)
3. Electrochemical Method for Atmospheric Corrosion Testing of Metals. V. Kucera and E. Mattsson. Proc. 7th Scand. Corrosion Congress, 1975, pp. 202-217. (Fe75-10)
4. Environmental Exposure System for Studying Air Pollution Damage to Materials. J. W. Spence, F. D. Stump, F. H. Haynie and J. B. Upham. NTIS Report PB-240615/5ST, January 1975, 46 pp. (Fe75-11)
5. Long Range Transportation of Air Pollutants and Corrosion Effects. S. Haagenrud and B. Ottar. Proc. 7th Scandinavian Corrosion Conference, 1975, pp. 102-105. (Fe75-13)
6. Sulfur Dioxide and Material Damage. D. G. Gillette. J. Air Pollution Control Assn., v. 25, No. 12, December 1975, pp. 1238-1243. (Fe75-17)

1974

1. Atmospheric Corrosion. H. Eyring, B. Robertson, C. C. Chu, and T. Andersen. Proc. Nat. Acad. Sci. USA, v. 71, No. 2, February 1974, pp. 245-247. (Fe74-3)
2. Corrosion Aggressivity of Model Regions of Czechoslovakia. D. Knotkova-Cermakova, B. Bosek, and J. Vlckova. Corrosion in Natural Environments, ASTM STP 558, American Society for Testing and Materials, 1974, pp. 52-74. (Fe74-8)
3. Corrosion of Metals in the Atmosphere. W. K. Boyd and F. W. Fink. MCIC Report 74-23, Battelle-Columbus Labs., Metals and Ceramics Information Center, Columbus, Ohio, August 1974, 77 pp. (Fe74-9)
4. Corrosivity of the Atmosphere. J. B. Hohler. Plating, v. 61, No. 1, 1974, pp. 62-65.

Corrosion of zinc and cadmium-coated steel panels exposed to the atmosphere was determined at various locations in the State of Washington.
5. Design of a Laboratory Experiment to Identify the Effects of Environmental Pollutants on Materials. J. W. Spence and F. H. Haynie. Corrosion in National Environments, ASTM STP 558, American Society for Testing and Materials, 1974, pp. 279-291. (Fe74-10)
6. Effect of Sodium Chloride on the Absorption of Water Vapor and Kinetics of the Atmospheric Corrosion of Zinc. P. V. Strekalov, Y. N. Mikhailovskii, and T. S. Balandina. Zashch. Metal., v. 10, No. 3, 1974, pp. 284-288 (Russian).

(The adsorption of water vapor on pure and NaCl-activated surfaces of Ag and zinc and the corrosion of zinc were investigated. For activation, quartz crystals covered with a thin layer of metal were immersed into a 0.06N NaCl solution, leaving 14 dry mg NaCl/m². The amounts of water adsorbed on pure Ag and on Ag having NaCl particles on it were practically the same; they increased with increasing relative pressure of water vapor. The kinetics of the adsorption of water from the gas phase on Ag are logarithmic. On zinc at a relative water content of 15 percent the amounts of water adsorbed were about the same on pure and on activated surfaces. But, at a relative water content >30 percent, the activated surface adsorbed more water than the pure surface. At 15 percent water, the surface of zinc carrying NaCl particles accumulated 1 to 2 molecular layers of water; with 75 percent water 12 to 14 were layers collected. The corrosion of zinc increased with increasing water-vapor pressure. The kinetics of interaction of water and NaCl with zinc are logarithmic. During 15 minutes exposure at a relative water content of 75 percent, corrosion of an activated zinc surface was 5 to 6 times as high as that of

the pure surface. The assumed reaction of zinc with chloride ion occurring in the adsorbed water layers are described.

7. Electrochemical Technique for Determination of the Instantaneous Rate of Atmospheric Corrosion. V. Kucera and E. Mattsson. Corrosion in Natural Environments, ASTM STP 558, American Society for Testing and Materials, 1974, pp. 239-260. (Fe74-15)
8. Examples On The Acid-Smut Fallout. M. Oyama, A. Moriyama, H. Miyazato, and H. Sakugawa. Okinawa-ken Kogai Eisei Kenhyusho-ho (Okinawa Prefect. Res. Inst. Pollut. Health), No. 8, 1974, pp. 32-33.

The acid-smut fallout that occurred in October 1974 in Okinawa Prefecture is described. The leaves of plants at the accident site showed 2 to 3 mm holes whose edges indicated the ashed condition, a typical observation after the sulfuric acid mist accident. Several corrosion spots were also observed on galvanized iron roofs. The suspected source was the main chimney of the Okinawa Petroleum Co., emitting sulfur dioxide at the rate of 420 N cu m/hr (12 ton/hr.). The damage was observed at the western side of the main chimney. Following the reported damage, the cleaning of the main chimney was done, yielding more than 10 drums full of acid-smut, more than 66% of which had particle sizes greater than 149 micron. The collected acid-smut was analyzed. The sulfuric acid content in the acid-smut was 30%. There was 6% iron and 60 ppm nickel in the acid-smut, as well as vanadium and copper (II).
9. Rapid Electrochemical Procedure to Measure the Atmospheric Corrosion Resistance. E. Erdos. Galvano-Organo, No. 443, April 1974, pp. 382-385 (French). (Cu74-7)
10. Seven-Year Exposure at Point Reyes, California. W. H. Ailor, Corrosion in Natural Environments, ASTM STP 558, American Society for Testing and Materials, 1974, pp. 75-81. (Al74-6)
11. Short-Term Atmospheric Corrosion of Various Copper-Base Alloys: Two and Four-Year Results. R. S. Herman, and A. P. Castillo. Corrosion in Natural Environments, ASTM STP 558, American Society for Testing and Materials, 1974, pp. 82-96. (Cu74-9)
12. The Economic Damages of Air Pollution. T. E. Waddell. NTIS Report PB-235701, 1974, 156 pp. (Fe74-21)
13. The Economics of Clean Air In Perspective. F. H. Haynie. Materials Protection and Performance, v. 13, No. 4, April 1974, pp. 33-38. (Fe74-22)

14. The Mode of Initial Reaction of SO₂ at a Metal Surface. J. R. Duncan and D. J. Spedding. Corros. Sci., v. 14, No. 4, 1974, pp. 241-249. (Fe74-23)
15. The Rust Preventing Mechanism of Zinc Dust Paints. F. Theiler. Corros. Sci., v. 14, No. 7, 1974, pp. 405-414.

In atmospheric weathering the rust preventing mechanism of zinc dust paints is dominated by the sealing action of the zinc corrosion products on the paint surface. Under immersed conditions the time of cathodic protection of bare steel is dependent on the zinc content of the paints. An optimum zinc content has been found for all of the tested binders: polystyrene, vinyl copolymer and chlorinated rubber. Differences in the optimum zinc content arise mainly due to the different wetting of the pigment by the binders.

16. The Use of Weather and Climatological Data in Evaluating the Durability of Building Components and Materials. L. W. Masters and W. C. Wolfe. NTIS Report COM-74-50841/7, August 1974, 102 pp. (Fe74-25)
17. Weather Factors Affecting Corrosion of Metals. P. J. Sereda. Corrosion in Natural Environments, ASTM STP 558, American Society for Testing and Materials, 1974, pp. 7-22. (Fe74-27)

1973

1. Accelerated Testing of Zinc and Cadmium for Atmospheric Corrosion in Climatic Chambers. Y. N. Mikhailovskii, L. A. Shuvakhina, and C. T'chi Hong Wang. Protection of Metals, v. 9, 1973, p. 135.

This article describes a method of determining corrosion constants by testing the metals in artificial-climate chambers. Results of a forecast of the corrosion of zinc and cadmium in various climatic regions are presented.

2. An Assessment of the Atmospheric Corrosion Resistance of Hot-Dipped Galvanized Steel After Five Years' Exposure. R. M. Evans. British Steel Corp. (England), Report No. BISRA-SM/569/C, April 1973, 19 pp.

The corrosion of hot-dipped galvanized steel has been assessed after five years at four sites. Corrosion rates and coating lives have been assessed for skyward and groundward facing aspects and for samples exposed in louvered boxes. At the two severest sites the loss of coating with time displayed rectilinear kinetics - indicative that the frequency of film repairing was sufficient only to maintain the 'status quo'. At the remaining sites the 'loss of coating-time' curves showed varying degrees of flattening - indicative of the establishment of protective films. The

influence of both environment and exposure condition on the corrosion of the zinc coating has been examined in the light of operative mechanisms.

3. Characterization of Bridge Locations by Corrosion and Environmental Measurements - First Year Results. J. S. Hutchins and M. McKenzie. Report No. TRRL-LR-550, Transport and Road Research Lab., Crowthorne, England, 1973, 29 pp. (Fe73-7)
4. Corrosion Caused by Perspiration. G. A. Tret'yakova and V. P. Barannik. Zashch. Metall., v. 9, No. 6, 1973, pp. 715-717 (Russian). (Fe73-9)
5. Initial Reactions of SO₂ After Adsorption on to Metals. J. R. Duncan and D. J. Spedding. Corros. Sci., v. 13, 1973, pp. 881-889. (Fe73-14)
6. Relation Between Environmental Pollution and Corrosion of Zinc and Galvanized Steel. N. Dreulle and P. Dreulle. Metall., v. 27, No. 10, October 1973, pp. 366-369 (German).*

Experimental data are cited to demonstrate that zinc and galvanized metal are susceptible to corrosion by sulfur dioxide in the air and that relatively high humidity of the air aggravates the effect. On the other hand, galvanizing of steel provides protection against corrosion by the salts used for de-icing of streets and in marine atmosphere.

7. Relation Between Environmental Pollution and the Corrosion of Zinc and Hot Galvanized Steel. N. Dreulle and P. Dreulle. Metall., v. 27, No. 6, 1973, pp. 626-628 (German).

Corrosion of zinc by air-containing sulfur dioxide was studied using samples of zinc roofs from industrial sections of various French cities. Galvanized steel protected by a paint coat was resistant to corrosion.

8. Relation Between Environmental Pollution and Corrosion of Zinc and Hot-Dip Galvanized Steel. N. Dreulle and P. Dreulle. Corros., v. 21, No. 2, 1973, pp. 114-119 (French).

This paper is a review with 10 references.

1972

1. Analyzing Atmospheric Corrosion. J. B. Mohler. Pollut. Eng., v. 4, No. 7, 1972, pp. 28-29. (Fe72-2)

2. Corrosion of Copper, Aluminum, and Zinc Alloys in a Sulfur Dioxide Atmosphere. St. Kopczynski. Ochrona przed korozja, v. 15, No. 6, 1972, pp. 149-154 (Polish). (A172-2)
3. Hot-Dip Galvanized Steel Sheet and Its Corrosion Resistance. N. Dreulle and P. Dreulle. Galvano, v. 41, No. 427, 1972, pp. 867-871 (French).

The reaction between zinc and iron during the galvanizing process, the reaction of zinc during atmospheric corrosion, and the effect of the reaction products on the protection of steel are reviewed. Corrosion rates in geographical areas of France with varying atmospheric conditions are given.

4. Interaction of Sulfur Dioxide with Moisture Adsorption Layers During Atmospheric Corrosion of Metals. P. V. Strekalov and Y. N. Mikhailovskii. Zashch. Metal., v. 8, No. 5, 1972, pp. 573-576 (Russian).*

At <100% humidity SO_2 adsorbs on zinc as monolayers, but at >100% humidity a stable $\text{SO}_2 \cdot 7\text{H}_2\text{O}$ clathrate is formed. Partial ionization of the hydrated SO_2 crystallohydrates which promote further corrosion.

5. Kinetics of Initial Stages of the Oxidation of Zinc in a Medium of Oxygen and Moist Air. Y. N. Mikhailovskii and P. V. Strekalov. Zashch. Metal., v. 8, No. 2, 1972, pp. 146-151 (Russian).*

A microweighing technique was used to study the kinetics of Zn oxidation and the adsorption of H_2O on fresh and oxidized Zn surfaces. Specimens were prepared by vacuum deposition of thin Zn films ($\sim 700\text{\AA}$) on quartz substrates (the film surface being determined by the adsorption of octane). Freshly deposited films were oxidized in dry O at 0.17-210 torr and the number of ZnO layers formed calculated from the weight increment. The results show that even at pressures as low as 0.17 torr, the increment exceeds the amount corresponding to a monolayer of chemisorbed oxygen. Periodic degassing showed that the amount of physically adsorbed oxygen was negligible. At $P_0 < 10$ torr and up to $\tau = 600$ sec, the growth of the oxide layer follows a logarithmic law, but at >10 torr, the slope of the $\eta = a + b \log \tau$ curves is steeper in the initial period of oxidation, indicating the potential existence of several oxidation mechanisms. The kinetics of physical adsorption of H_2O obeys the logarithmic law over the entire range of pressures examined. If the surface area occupied by mole of H_2O is assumed to be $10 \text{ \AA}^2$, it is evident that the thickness of the physically-adsorbed film does not exceed 10-11 monolayers even at 100% humidity. The amount of chemisorbed and physically adsorbed H_2O does not change with the state of the Zn surface and the regularities observed for fresh nonoxidized Zn are entirely preserved when adsorbing H_2O on the surface of preliminary oxidized Zn. Chemisorbed H_2O hinders the oxidation of Zn in air. It is possible that the adsorption of H_2O is accompanied by its dissociation, the OH ions reacting with Zn to give ZnOH and Zn(OH)_2 . This inhibiting layer of OH ions hinders the formation of atomic oxygen and consequently the oxidation of Zn.

6. Mechanism of Rusting Under Different Conditions. U. R. Evans. Brit. Corros. J., v. 7, 1972, p. 10. (Fe72-14)
7. Reactions of Sulfur Dioxide With Adsorbed Layers of Moisture Under Conditions of Atmospheric Corrosion of Metals. P. V. Strekalov, and Y. N. Mikhailovskii. Zashch. Metall., v. 8, No. 5, 1972, pp. 573-576 (Russian). (Fe72-16)
8. Survey on the Metal Corrosion by Air Pollution: Effect of Glauber's Salt on Metals. T. Nagano, A. Hattori, T. Nagai, Y. Ukishima, Y. Nakai, and I. Iwasaki. Shizuoka-ken Eisei Kenkyusho Nenpo, No. 16, 1972, pp. 217-226 (Japanese). (Fe72-18)
9. The Influence of the Relative Humidity and Corrosion Products on the Adsorption of Sulfur Dioxide on Metal Surfaces. T. Sydburger and N. G. Vannerberg. Corros. Sci., v. 12, No. 10, 1972, pp. 775-784. (Fe72-22)

1971

1. Atmospheric Corrosion of Galvanized Steel. K. B. Barton. Proc. 9th Int. Conf. Hot Dip Galvanizing (1970), Ind. Newspapers Ltd., London, 1971, pp. 199-206. (Fe71-4)
2. Atmospheric Corrosion of Metals. M. Arpaia. Atti Not. Assoc. Ital. Metall., v. 26, 1971, pp. 363-367 (Italian). (Fe71-5)
3. Atmospheric Tests. S. K. Coburn. Chapt. 17 in Handbook on Corrosion Testing and Evaluation, edited by W. H. Ailor, Electrochemical Society, Corrosion Monograph Series, J. Wiley, N.Y., N.Y., 1971, pp. 475-505. (Fe71-6)
4. Calculation of the Rate of Atmospheric Corrosion of Zinc and Cadmium Coatings in Various Climatic Regions. Y. N. Mikhailovskii, G. B. Klark, L. A. Shuvakhina, A. P. San'ko, Y. P. Gladkikh, and V. V. Agafonov. Zashch. Metal., v. 7, No. 5, 1971, pp. 534-539 (Russian).**

The effect was studied of various meteorological factors (such as humidity, air temperature, duration of wetting of the metal by various forms of moisture, etc.) on the atmospheric corrosion rate of zinc and cadmium in various climatic regions of the USSR. Corrosion data were obtained by using a system of monitoring units which permitted uninterrupted recording of the corrosion. Corrosion was a function of the attack due to adsorbed electrolyte and various phases of moisture (rain, dew, etc). The corrosion rate of zinc due to an adsorbed film and that due to a film phase was 8.3×10^{-4} and 4.0×10^{-3} g/m²hr, respectively,

and for cadmium it was 1.2×10^{-3} and 6.0×10^{-3} g/m²hr, respectively. A linear dependence was observed between the corrosion rate of zinc or cadmium and the time of wetting of the metal by adsorbed or by various phases of moisture. The effect of a mixture of sulfur dioxide and Cl⁻ is given. A new method for calculating the atmospheric corrosion rates of zinc and cadmium is suggested.

5. Corrosion of Metals by Sulfur Dioxide. G. K. Singhania, B. Lal, and B. Sanyal. Labdev. Part A, v. 9, No. 3 & 4, 1971, pp. 214-216. (Fe71-10)
 6. Corrosion of Zinc. J. F. H. Von Eijnsbergen. Korrosion och Ytskydd, v. 6, No. 12, 1971, pp. 18-21 (Swedish).
- The correlation between climate and corrosion of zinc by SO₂ has been investigated and the mechanism of corrosion of zinc and of zinc plus paint coatings is discussed.
7. Metal Coatings on Steel at Lighthouse Beach, Lagos. J. F. Stanners. Brit. Corrosion J., v. 6, No. 5, Sept. 1971, pp. 211-215. (Fe71-17)
 8. Technical-Economic Evaluation of Air-Pollution Corrosion Costs on Metals in the U.S. F. W. Fink, F. H. Buttner, and W. K. Boyd. NTIS Report PB-198453, February 19, 1971, 160 pp. (Fe71-25)

1970

1. Corrosion Behavior of the Major Architectural and Structural Metals in Canadian Atmospheres. Summary of Ten-Year Results of Group I. E. V. Gibbons. Nat. Res. Council. Can., Div. Bldg. Res., Tech. Paper No. 328, 1970, 21 pp. (Fe70-5)
2. Determination of Microclimates as Atmospheric Corrosion Factors. Atmospheric Corrosion of Zinc. R. Deswaef. Trib. CEBEDEAU, v. 23 No. 314, 1970, pp. 24-28 (French).**

The microclimates which were factors in the corrosion of zinc included: relative humidity; precipitation; wind velocity and frequency; the concentration of SO₂, CO₂, H₂S, and Cl⁻ in the air; and the amount, size, morphology, and composition of deposited dusts. All of these parameters were determined at the Lighthouse and Jetty at Ostend, Eupen, and Liege in winter and summer. The values at Ostend were lower except for Cl⁻ and sand than at Eupen or the steel center of Liege. The corrosion of zinc was the result of a balance of the protective action of a layer of basic carbonate formed in moist air and the deleterious effects of SO₂, H₂S and Cl⁻.

3. Effects of Atmospheric Sulfur Dioxide on the Corrosion of Zinc.
F. H. Haynie and J. B. Upham. Materials Prot. Perform., v. 9, No. 8, 1970, p. 35.*

The amount of sulfur dioxide in the air is the major factor in determining the rate of corrosion of zinc. Because little, if any, zinc corrosion would occur in a nonmarine environment if sulfur dioxide were not present, the reduced life of galvanized products can be directly attributed to air pollution.

4. Kinetics of Iron and Zinc Corrosion in a Humid Medium. A. M. Zinevich, E. I. Sergeeva, Yu N. Mikhailovskii, and V. B. Serafimovich. Zashch. Metal, v. 6, No. 3, 1970, pp. 333-336 (Russian). (Fe70-9)
5. Metallic Coatings for the Protection of Mild Steel From Corrosion at Ambient Temperatures - 1. Introduction and Zinc Coatings. C. Davies and N. J. Hanford. Corrosion - Anticorrosion, v. 17, No. 6, 1970, pp. 11-16.

The performance of coated steel articles depends upon the thickness of the coating and not upon the technique used for deposition. Five different zinc coatings processes are complementary to each other rather than in competition, and it is rare that more than two processes can be seriously considered as the best choice for a particular application. Hot-dip galvanizing has the advantage that the work-piece is thoroughly covered and can produce a thick coating of 550-680/gm². It is also the most economical process for large production of coated strip and lends itself easily to a continuous process. Many modifications have been made over the years to increase efficiency.

6. Properties of Electrolyte Films Formed Through Atmospheric Corrosion.
D. Knotkova-Cermakova and J. Vlckova. Werkst. Korros., v. 21, No. 1, 1970, pp. 16-21 (German). (Fe70-10)
7. Reaction between SO₂ and Wet Metal Surfaces. N. G. Vannerberg and T. Sydberger. Corros. Sci., v. 10, 1970, pp. 43-49. (Fe70-11)
8. Systems Analysis of the Effects of Air Pollution on Materials.
R. L. Salmon. NTIS Report PB-209192, January 15, 1970, 196 pp. (Fe70-13)
9. The Weathering and Performance of Building Materials. J. W. Simpson and P. J. Horrobin, eds., Medical and Technical Publishing Co. Ltd., 1970, 277 pp. (Fe70-17)

10. Use of Environmental Data in Atmospheric Corrosion Studies.
J. F. Stanners. Brit. Corros. J., v. 5, No. 3, 1970, pp. 117-121.
(Fe70-18)
11. What to Consider in Specifying Zinc Coatings. E. W. Horvick. Metal
Progress, v. 97, No. 6, 1970, pp. 125-134.

Two major points are the function of the product and its intended service life. The product should be designed with the efficient and economical application of a corrosion-resistant zinc coating in mind.

1969

1. Aluminum Corrosion at Urban and Industrial Locaiton. W. H. Ailor, Jr.
Proc. American Soc. Cilvil Enger., Journal of the Structural Division,
October 1969, pp 2141-2160. (Fe69-21)
2. Calculation of Moistening and Metallic Corrosion in Atmospheric
Environment. A. I. Golubev and M. Kh. Kadyrov. Proc. 3rd Intern.
Congr. on Metallic Corrosion, Moscow (1966), Swets-Zeitlinger,
Amsterdam, Holand, v. 4, 1969, pp. 522-531. (Fe69-24)
3. Corrosion of the Atmosphere. P. Atterby. NTIS Report N71-26259, November
1969, 9 pp. (Swedish). (Fe69-25)
4. Corrosion of Metals in the Tropics. B. Sanyal, G. K. Singhanian, and
J. N. Nanda. Proc. 3rd Intern. Congr. on Metallic Corrosion, Moscow
(1966), Swets-Zeitlinger, Amsterdam, Holland, v. 4, 1969, pp. 542-543.
(Fe69-26)
5. Effect of the Atmospheric Corrosion Products on Electrochemical Behaviour
of Metals. G. B. Clark, G. K. Berukshtis, and Z. I. Ignatova. Proc.
3rd Intern. Congr. Metallic Corrosion, Moscow (1966), Swets-Zeitlinger,
Amsterdam, Holland, v. 4, 1969, pp. 406-412. (Fe69-28)
6. Evaluation of Atmospheric Corrosion Tests With Iron, Copper, and Zinc
Extending Over Three Years, at Czechoslovak Testing Stations. K. Barton
and Z. Bartonova. Werkst. Korros., v. 20, No. 2, 1969, pp. 87-93
(German). (Fe69-30)
7. Painting of Metal Sprayed Structural Steelwork--Report on Conditions of
Specimens after Five Years' Exposure. J. F. Stanners and K. O.
Watkins. Australasian Corrosion Eng., v. 13, No. 10, October 1969,
pp. 7-17. (Fe69-34)

8. Protection of Steel in the Atmosphere by Sprayed Metallic Coatings. S. Klemantaski and J. F. Stanners. Proc. 3rd Intern. Congr. on Metallic Corrosion, Moscow (1966), Swets-Zeitlinger, Amsterdam, Holland, v. 4, 1969, pp. 509-521. (A169-8)

1968

1. Composition and Structure of Natural Patinas. II. Zinc and Zinc Alloys. 1872 to 1965. S. Z. Lewin and S. M. Alexander. Art Archaeol. Tech. Abstracts, v. 7, No. 2, 1968, pp. 151-171.*

The initial Zn-containing product that forms as a result of the attack of air and water in the combination on Zn or brass is Zn(OH)_2 . This product, when formed under nearly neutral conditions (e.g. in natural corrosion of buried or exposed objects) is an amorphous, flocculent material that changes readily into other forms, e.g. crystallographic varieties of Zn(OH)_2 , ZnO , or any of a number of hydroxy salts of Zn. There is greater diversity among the products formed on Zn and brass surfaces by corrosion under laboratory conditions or natural exposure conditions than has so far been shown to exist in the form of natural minerals in nature. Additional research employing modern instrumental techniques of phase analysis and identification is necessary before the determination of compositions and textures of patinas on Zn or brass artifacts is to become a useful tool in the elucidation of their age, history, or authenticity.

2. Corrosion of Metals by Aqueous Solutions of the Atmospheric Pollutant Sulfurous Acid. W. McLeod and R. R. Rogers. Electrochem. Technol., v. 6, No. 7-8, July-August 1968, pp. 231-235. (Fe68-3)
3. Effect of One Percent Copper Addition on the Atmospheric Corrosion of Rolled Zinc. S. R. Dunbar. Metal Corrosion in the Atmosphere, ASTM STP 435, American Society for Testing and Materials, 1968, pp. 308-325.

The corrosion characteristics of a common zinc alloy containing 1 percent copper and an unalloyed grade were evaluated after 2 and 7 years of exposure in industrial, marine, and rural atmospheres. The usefulness of tension tests for determining corrosion rates was explored. Zinc composition did not significantly influence corrosion rates. Pitting occurred in the copper-bearing alloy, presumably as a result of galvanic action. Tensile properties of the zinc alloy were not significantly affected after the 7 years of exposure. The corrosion rates were highest in the industrial atmosphere and lowest in the rural atmosphere. Tension test data indicated that aging effects prevent a correlation of tensile strength and elongation with corrosion rates.

4. Effects of Atmospheric Factors on the Corrosion of Rolled Zinc.
H. Guttman. Metal Corrosion in the Atmosphere, ASTM STP 435, American Society for Testing and Materials, 1968, pp. 223-239.

A long-term exposure program has been carried out at Birchbank, B.C., wherein rolled zinc corrosion data and certain atmospheric factor data were developed. Zinc is sensitive to variations in climatic and atmospheric pollution conditions, and as a result panels exposed on different dates for a specific period of time can corrode at different rates. An empirical equation has been developed for Birchbank which relates corrosion of zinc to the time of wetness of exposed panels and the average atmospheric sulfur dioxide content during the time panels are wet. The equation accounts for most of the observed variation in corrosion losses and is valid for exposure periods of up to 256-weeks' duration. This paper also presents information concerning the relative corrosion rates of the skyward and groundward surfaces of zinc panels, the relationship between atmospheric sulfur dioxide as measured by a Thomas autometer and by the lead peroxide method.

5. Increased Connector Contact Reliability. M. Ball, F. H. Hardie and E. J. Struckus, The Electronic Engineer, March 1968, pp. 82-85. (Al68-6)
6. Investigations of the Corrosion-Causing Properties of Volatile Acids and Anhydrous Acids. E. Iaengle. Eidgenoessische Technischen Hochschule, Zurich, Switzerland. Ph.D. Thesis, 1968, 43 pp. (German). (Fe68-11)
7. Measurement of Atmospheric Factors Affecting the Corrosion of Metals.
H. Guttman and P. J. Sereda. Metal Corrosion in the Atmosphere, ASTM STP 435, American Society for Testing and Materials, 1968, pp. 325-359 (Fe68-12)
8. Mechanism and Kinetics of Corrosion in a Moist Atmosphere in the Presence of Hydrogen Chloride Vapors. K. Barton and Z. Bartonva. Tr. Mezhdunar. Kongr. Korroz. Metal., 3rd (1966), edited by N. D. Lesteva, Izd. "Mir", Moscow, USSR, v. 4, 1968, pp. 493-506 (Russian). (Fe68-13)
9. Stability of Metal Coatings in Corrosive Media. A. Kovachev, N. Stoyanova, M. Boncheva, S. Simov, S. Avramova, B. Grigorov, and B. Gochev. Elektroprom. Priborostr., v. 3, No. 3, 1968, pp. 105-107. (Fe68-18)

1967

1. Bridging with Steel. J. A. Cran and I. M. Park. Engineering J., February 1967, pp. 18-25. (Fe67-3)

2. Corrosion by Air Pollution. J. R. Goss. Proc. Annu. Conf., Nat. Soc. Clean Air, No. 34, 1967, pp. 75-92. (Fe67-4)
3. Mechanism of the Corrosion of Fe, Zn, and Cu in a Humid Atmosphere Containing HCl Vapors. K. Barton and Z. Bartonova. Collect. Czech. Chem. Commun., v. 32, No. 7, 1967, pp. 2431-2438 (German). (Fe67-6)
4. The Hot Dip Galvanizing Industry. F. C. Porter. Metallurgia, v. 75, No. 6, 1967, pp. 241-247.

In this survey of the hot dip galvanizing industry, the author begins with a brief history of the process and then proceeds to an account of the development of sheet, wire, tube and general galvanizing before discussing the fabrication of galvanized steel, painted galvanized sheet and the economic case for galvanizing. He concludes with a series of characteristic examples of the use of galvanizing in the constructional and transport industries.

1966

1. Atmospheric Corrosion of Metals At Bhavnagar. V. S. Rao. Indian J. Technol., v. 4, No. 5, 1966, pp. 159-161. (Fe66-3)
2. Atmospheric Corrosion of Steel, Zinc, Cadmium, Copper, and Aluminum in Different Coastal and Continental Regions. G. K. Berukshtis and G. B. Klark. Corrosion of Metals and Alloys, Collection No. 2, Israel Program for Scientific Translations, Jerusalem, 1966, pp. 281-297. (Fe66-4)
3. Atmospheric Corrosion of Zinc- and Cadmium-Coated Steel and the Coefficients for Recalculating the Results of Accelerated Corrosion Tests Into Data for Service Conditions. P. V. Strekalov and G. K. Berukshtis. Corrosion of Metals and Alloys, Collection No. 2, pp. 221-233.

In this article, the authors compare the results of prolonged atmospheric corrosion tests on zinc and cadmium plates with the results of accelerated corrosion tests on these deposits in three chambers: (1) "heat and moisture," (2) "sulfurous gas," and (3) "sea mist." The approximate coefficients for comparing the results of accelerated tests with those of field tests were determined.

4. Corrosion Behavior of Salt Powder Towards Various Metals. a. Bukowiecki and B. G. Joshi. Schweiz. Arch. Angew. Wiss. Tech., v. 32, No. 2, 1966, pp. 42-54. (Fe66-5)

5. Corrosion Behavior of Some Metallic Materials in Liquid Sulfur Dioxide.
L. Rivola, T. Bazzan, M. Piro, and G. Bombara. Proc. 2nd Intern. Congr. Metal. Corrosion, New York, (1963), National Association of Corrosion Engineers, Houston, TX 1966, pp. 418-423. (Fe66-6)
6. How Atmospheric Conditions Can Corrode Refinery Equipment.
P. W. Sherwood. Enodel Kohle (Hamburg), v. 19, No. 4, April 1966, pp. 289-290 (German). (Fe66-7)

1965

1. Atmospheric Corrosion of Steels Related to Meteorological Factors in Japan. III. Results of Weathering Tests Conducted on Metallic Coatings for 3 Years. K. Oma, T. Sugamo, T. Ueki, and Y. Hirai. Boshoku Gijutsu, v. 14, No. 1, 1965, pp. 16-19 (Japanese). (Fe65-2)
2. Atmospheric Corrosion Products of Some Commercial Metals. H. J. Meyer. Korrosion, No. 17, 1965, pp. 44-52 (German). (Fe65-3)
3. Materials Deterioration and Air Pollution. J. B. Upham. J. Air Pollution Control Association, v. 15, No. 6, June 1965, p. 265. (Fe65-14)
4. Significance of Corrosion Testing Process with Special Consideration of the SO₂ Test According to DIN 50018. W. Kesternich. Werkst. Korrosion, v. 16, 1965, pp. 193-201 (German). (Fe65-15)
5. Systematic Corrosion Tests With Galvanic Coatings in a Sulfur Dioxide Atmosphere. A. Kutzelnigg. Werkst. Korros., v. 16, No. 9, 1965, pp. 750-754 (German). (Fe65-16)
6. The Significance of Sulfur Dioxide in the Atmospheric Corrosion of Metals. G. Schikorr. Korrosion, No. 17, 1965, pp. 27-34. (Fe65-20)

1964

1. An Electrical Resistance Method for Measuring Rates of Corrosion of Electrodeposited Metals in Laboratory Tests. F. Enrico, V. Riccio, and B. Martini. Product Finishing, v. 17, No. 5, May 1964, pp. 74-79. (Cu64-1)
2. Corrosion Behavior of Zinc and Zinc Coatings Exposed to the Atmosphere. G. Schikorr. Werkst. Korros., v. 15, No. 7, 1964, pp. 537-543.

The corrosion behavior of zinc in the atmosphere is generally satisfactory except under conditions of high humidity, and when high humidity is combined with sulfur oxides.

3. The Influence of Sulphur Dioxide on the Atmospheric Corrosion of Metals. G. Schikorr. Werkst. Korros., v. 15, No. 5, 1964, pp. 457-463 (German). (Fe64-4)

1963

1. What Price Maintenance-Free Structures? J. C. Pohlman. Electrical World, v. 159, 1963, pp. 72-74. (Fe63-7)

1962

1. Aluminum Alloys Corrosion Behavior in an Industrial Environment. F. F. Booth and K. G. Latimer. Corrosion Technology, v. 9, No. 11, 1962, pp. 315-320 (Fe62-1)
2. Atmospheric Corrosion by Electrolyte Nuclei. B. Sanyal and D. V. Bhadwar. J. Sci. Industr. Res., v. 21D, 1962, p. 243. (Fe62-2)
3. Atmospheric Corrosion of Metals. Some Questions of Theory. I. L. Rosenfel'd. Proc. 1st Intern. Congr. on Metallic Corrosion, London (1961), Butterworth, London, 1962, pp. 243-248. (Fe62-3)
4. Comparative Outdoor Exposure Tests of Electrodeposited Zinc and Cadmium Coatings on Steel in a Natural Industrial Atmosphere. T. Biestek. Proc. 1st Intern. Congr. on Metallic Corrosion, London (1961), Butterworth, London, 1962, pp. 269-274.

The corrosion resistance of electrodeposited zinc coatings on steel (obtained both from a cyanide and from a sulphate bath) and of cadmium coatings, in a natural industrial atmosphere was tested. The thickness of the tested coatings deposited on flat steel test panels was 1, 2, 4, 7, 15 and 30 microns. A visual inspection rating was used.

The zinc coatings obtained from the cyanide bath showed twice the service life of cadmium coatings of corresponding thickness, and showed a longer service life than those from the sulphate bath.

The rates of corrosion for the particular exposure location, in microns per year were different for each kind of coating; for zinc coatings deposited from a cyanide bath 4 to 6 microns, for zinc coatings deposited from a sulphate bath 6 to 9 microns, and for cadmium coatings 9 to 12 microns per year.

The results of outdoor exposure tests were compared with those of three accelerated tests (spray with 3 percent NaCl solution, spray of a

solution containing four different salts including ammonium sulphate and ammonium chloride and an artificial industrial atmosphere test) and some effort has been made to establish the approximate correlation factors between the results of field tests and individual accelerated tests. The calculated correlation factors were different for each accelerated test and for each kind of coating. The deviations of extreme values of these factors from the mean value did not exceed 25 percent and were on average about ± 10 percent.

The corrosion-time curves of zinc and cadmium electrodeposited coatings showed that the protective properties are approximately proportional to the thickness.

5. Corrosion Evaluation of Improved Wrought Zinc Alloy. E. L. White, P. D. Miller, and W. K. Boyd. Materials Protection, v. 1, No. 1, January 1962, pp. 56-58.

This paper reports on of laboratory studies to determine corrosion resistance of new wrought Zn-Cu-Ti alloy, called Hydro-T-Metal, developed for use in architectural and structural applications. Relative humidity, air-sulfur dioxide and alternate immersion experiments are described. These accelerated laboratory tests indicate that corrosion resistance of the new alloy is equal or slightly superior to that of rolled zinc and galvanized steel.

1961

1. Atmospheric Corrosion. U. R. Evans. Chapt. 8 in The Corrosion and Oxidation of Metals, Edward Arnold Ltd, 1961, pp. 481-535. (Fe61-2)
2. Atmospheric Corrosion Tests of Electroplated Coatings. T. Biestek. Prace Inst. Mech. Procyzyjnej, v. 9, No. 31, 1961, pp. 39-49. (Fe61-4)
3. Corrosion In Buildings. P. J. Sereda. Canadian Building Digest. Report No. CBD-20, August 1961, 4 pp. (Fe61-5)
4. Equivalence of the Atmospheric Corrosion of Zinc and Nickel to that of Sulfur Dioxide Absorbed from the Air. G. Schikorr. Metall, v. 15, 1961, pp. 981-987. (Ni61-3)

1960

1. Chemical Resistance to Ammonia of Construction Materials. A. E. Missan. Trudy Gosudarst. Inst. Priklad. Khim., v. 44, 1960, pp. 112-127 (Russian). (Fe60-3)

2. Theory of Atmospheric Corrosion of Metals. N. D. Tomashov. Trudy Inst. Fiz-Khim., Akad. Nauk S.S.S.R., No. 8, 1960, pp. 14-40 (Russian). (Fe60-7)

1959

1. Corrosion of Metals in Synthetic Atmospheres Containing Sulfur Dioxide. B. Sanyal and D. V. Bhadwar. J. Sci. and Ind. Research (India), v. 18A, February 1959, pp. 69-74. (Fe59-3)
2. Design and Interpretation of Atmospheric Corrosion Tests. H. R. Copson. Corrosion, v. 15, No. 10, October 1959, pp. 533t-541t. (Fe59-4)
3. Measurement of Surface Moisture. P. J. Sereda. ASTM Bulletin No. 238, 1959, pp. 61-63.

A cell of Pt and Zn was used to measure the surface moisture on metal panels exposed to outdoor conditions. It was used to determine the period of wetness for metal corrosion studies.

4. Mechanisms by Which Nonferrous Metals Corrode in the Atmosphere. P. M. Aziz and H. P. Goddard. Corrosion, v. 15, No. 10, 1959, pp. 529t-533t. (Al59-3)
5. Reaction Mechanism for the Atmospheric Corrosion of Metals in Damp and Sulfur Dioxide-Containing Air. K. Barton and E. Beranek. Werkst. Korros., v. 10, 1959, pp. 377-383. (Fe59-7)
6. Report of Sub-Committee VII, On Corrosiveness of Various Atmospheric Test Sites as Measured by Specimens of Steel and Zinc. Proc. American Society for Testing and Materials, v. 59, 1959, pp. 174-201. (Fe59-8)

1958

1. Corrosion of Zinc Plated Steel. R. H. Wolff. Metal Finishing, v. 56, No. 6, June 1958, pp. 46-52.

Corrosion behavior was studied by determining weight changes of coated specimens exposed to conditions of 20 percent salt fog and outdoor exposure in semi-industrial area. The weight change of untreated zinc increase to maximum at uniform rate, dependent upon ambient conditons, and decrease after maximum at same approximate rate. The weight change of chromated zinc varied slightly during the period of maximum weight of untreated zinc, and then decrease at the same rate as latter.

2. Influence of Dust and the Atmospheric Corrosion of Metals. K. Barton. Werkst. Korros., v. 9, Aug.-Sept. 1958, pp. 547-549 (German). (Fe58-7)

1957

1. The Effects of Air Pollution on Buildings and Metalwork. R. J. Schaffer. Air Pollution, edited by M. W. Thring, Butterworth Scientific, London, 1957, pp. 58-71. (Fe57-5)

1956

1. Atmospheric Corrosion of Metals. B. Sanyal and G. K. Singhania. J. Sci. Ind. Research (India), v. 15B, 1956, pp. 448-455. (Fe56-4)
2. Corrosion Studies. X. The Mechanism of the Atmospheric Corrosion of Metals in Moist Atmospheres Contaminated With Sulfur Dioxide. K. Barton and E. Beranek. Chem. Listy, v. 50, 1956, pp. 1388-1398. (Fe56-6)
3. Galvanic-couple Corrosion Studies by Means of the Threaded Bolt and Wire Test. K. G. Compton and A. Mendizza. Atmospheric Corrosion of Nonferrous Metals, ASTM STP 175, American Society for Testing and Materials, 1956, pp. 116-125. (Fe56-7)
4. Report of Subcommittee on Atmospheric Corrosion. H. R. Copson. Atmospheric Corrosion of Non-Ferrous Metals, ASTM STP 175, American Society for Testing and Materials, 1956, pp. 3-19. (Al56-4)
5. Resistance of Aluminized Steel to Atmospheric Corrosion. J. C. Merritt and W. E. McFee. Iron Age, v. 178, No. 26, 1956, pp. 60-61. (Al56-5)
6. The Atmospheric Corrosion of Rolled Zinc. E. A. Anderson. Atmospheric Corrosion of Non-Ferrous Metals, ASTM STP 175, American Society for Testing and Materials, 1956, p. 126.

The corrosion of zinc in the atmosphere is controlled by three principal factors: (1) the frequency of rain and dewfall, (2) the acidity of the moisture, and (3) the rate of drying. The corrosion rate is a maximum in industrial locations which combine acidic atmospheric contamination with prevalence of heavy mists and dew. The composition of zinc has only a minor bearing on the corrosion rate. Corollary data are presented which explain the findings in exposure tests conducted by Subcommittee VI (on Atmospheric Corrosion) of Committee B-3 on Corrosion of Non-Ferrous Metals and Alloys.

1955

1. Atmospheric Galvanic Couple Corrosion. K. G. Compton, A. Mendizza, and W. W. Bradley. Corrosion, v. 11, No. 9, 1955, pp. 35-44. (Fe55-1)
2. Metal Coatings on Steel in Contact With Aluminum Alloys. Some Comparative Corrosion Tests. S. C. Britton and R. W. de Vere Stacpoole. Metallurgia, v. 52, 1955, pp. 64-70. (Fe55-4)

1953

1. Effect of Climate and Atmospheric Pollution on Corrosion. J. C. Hudson and J. F. Stanners. J. Applied Chemistry (London), v. 3, pt. 2, February 1953, pp. 86-96. (Fe53-4)
2. Effect of Impurities in Metal on Rate of Corrosion of Zinc and Galvanized Coatings in Atmosphere. P. T. Gilbert. J. Applied Chemistry, v. 3, pt. 4, April 1953, pp. 174-181.

Atmospheric exposure tests are summarized under two headings: effect of additions to galvanizing bath on corrosion resistance of hot dipped coatings, and behavior of rolled zinc sheets of differing purity.

1952

1. Corrosion of Different Metals in Liquefied Sulfur Dioxide. J. Bollinger. Schweiz. Arch. angew. Wiss. u. Tech., v. 18, 1952, pp. 321-342. (Fe52-2)

1949

1. Effect of Weather on the Initial Corrosion Rate of Sheet Zinc. O. B. Ellis. Proc. Am. Soc. Testing Materials, v. 49, 1949, pp. 152-167, discussion, pp. 168-170.

The loss of weight of zinc sheet specimens exposed for 28 days in a mild industrial atmosphere was correlated with weather variations during that period. The number of hours of rainfall and of a relative humidity near 100 percent during the first five days of exposure had a significant effect upon the total loss of weight. After the first five days, the influence of these factors was much less. Samples of high initial corrosion also showed a higher corrosion rate after 12-month exposure. On samples of low-copper iron sheets no such influence of initial weather conditions was observed.

1948

1. The Atmospheric Corrosion of Metals. G. Schikorr. Arch. Metallkunde, v. 2, 1948, pp. 223-230 (German). (Fe48-7)

1943

1. The Corrosion of Metals in Air. Jubilee Memorial Lecture. W. H. J. Vernon. Chemistry and Industry, August 1943, pp. 314-318. (Fe43-1)

1939

1. Effects of Sulfur Compounds in the Atmosphere on Various Materials. L. R. Burdick and J. F. Barkley. U.S. Bureau of Mines, I. C. 7064, April 1939, 9 pp. (Fe39-1)

1936

1. Corrosion Resistance of Metals and Alloys. r. J. McKay and R. Worthington. Reinhold Publishing Corporation, New York, 1936. (Fe36-2)

1935

1. The Effect of Five Years' Atmospheric Exposure on the Breaking Load and the Electrical Resistance of Non-Ferrous Wires. J. C. Hudson. J. Inst. Metals, v. 56, 1935, pp. 91-102. (Cu35-1)

1929

1. The Relative Corrodibilities of Ferrous and Non-Ferrous Metals and Alloys. Part II--The Results of Seven Years' Exposure to air at Birmingham. J. N. Friend. J. Inst. Metals, v. 42, 1929, pp. 149-155. (Fe29-2)

OTHER METALS

1982

1. Atmospheric Corrosion of Fastener Joints. E. Taylor. Extended Abstracts, International Symposium on Atmospheric Corrosion (October 5-10, 1980, Hollywood, Florida), Electrochemical Society, v. 80-2, 1980, pp. 609-610. (Fe82-7)
2. Atmospheric Corrosion of Large Aircraft: Predicting Damage and Maintenance Requirements. R. Summitt and F. T. Fink. Extended Abstracts, International Symposium on Atmospheric Corrosion (October 5-10, 1980, Hollywood, Florida), Electrochemical Society, v. 80-2, 1980, pp. 603-604. (Al82-7)
3. Atmospheric Corrosion of Lead and Its Alloys. A. R. Cook and R. Smith. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 393-404.

The performance of lead exposed to the atmosphere is shown to be outstanding. Instances are cited of satisfactory service for hundreds of years with performance improving under industrial conditions due to formation of a protective barrier coating of lead sulfate. The results of long-term ASTM tests are given to demonstrate this performance. The behavior of lead and lead-tin alloy coatings on steel, both hot dip and electroplated, is described as dependent on the initial integrity of the coating. Results of exposure tests are provided showing outstanding performance under a variety of conditions of very thin pore-free electroplated coatings.

4. Atmospheric Corrosion of Magnesium and its Alloys in the Tropics. L. L. Gruss, F. Pearlstein, and L. Teitel. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 405-414.

Magnesium specimens were exposed at several exposure sites (marine, open-field, and rain forest) in the Panama Canal Zone and corrosion weight losses determined. These studies include four year exposures of bare AZ31b alloy, effect of environmental factors, effect of soil burial, effect of chromating magnesium, groundward vs. skyward corrosion, corrosion of magnesium alloys (cast AZ91b and LA142 vs. AZ31b), and the effect of various inorganic and organic paint systems applied to the highly corrodible AZ91b cast magnesium. The results of the above studies are interpreted and discussed.

5. Atmospheric Corrosion of the Less Common Metals. J. E. Castle. Extended Abstracts, International Symposium on Atmospheric Corrosion (October 5-10, 1980, Hollywood, Florida), Electrochemical Society, v. 80-2, 1980, p. 500.

Our understanding of the atmospheric corrosion of metals is at a turning point as new surface analytical methods come to be applied to this problem. The analytical information complements the kinetic data available from weathering trials and generally reveals the presence of oxy-hydroxide surface layers. There has been much less study of the surfaces of the less common metals after atmospheric exposure than after exposure to pure oxygen atmospheres. The trend, again, is to the formation of hydrated surfaces.

6. Atmospheric Corrosion Testing of Electrodeposited Coatings in Tropical China. T. Biestek. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 775-786. (Ni82-2)
 7. Atmospheric Corrosion Testing of Electrodeposited Zinc and Cadmium Coatings. T. Biestek. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 631-644. (Zn82-16)
 8. Colloid and Surface Phenomena in the Corrosion of Metals. E. Matijevic. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 123-138. (Fe82-28)
 9. Corrosion Aggressivity of Atmospheres (Derivative and Classification). D. Knotkova-Cermakova and K. Barton. Atmospheric Corrosion of Metals, edited by S. W. Dean, Jr., and E. C. Rhea, American Society for Testing and Materials, ASTM STP 767, 1982, pp. 225-249. (Fe82-31)
 10. Corrosion Behavior of Lean Uranium - Titanium Alloys. A. S. Nagelberg and D. K. Ottesen. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 553-560.
- The oxidation rates of uranium alloys containing 0.8, 1.0, 1.5, and 2.0 w/o titanium have been measured in a moist nitrogen atmosphere of 95% relative humidity at 70°C. The increase in titanium content from 0.8 to 2.0 w/o resulted in a 100-fold decrease in the extent of oxidation. The initial oxidation rates for all samples were high but became minimal after approximately 100 hr. Fourier transform infrared spectra and x-ray diffraction studies of the oxide scales indicated a change from a complex oxide to a simpler oxide-structure as the titanium content was increased.
11. Corrosion Performance of Decorative Electrodeposited Nickel and Nickel Iron Alloy Coatings. G. A. DiBari, G. Hawks, and E. A. Baker. Atmospheric Corrosion of Metals, edited by S. W. Dean, Jr., and E. C. Rhea, American Society for Testing and Materials, ASTM STP 767, 1982, pp. 186-213. (Ni82-5)

12. Economic Assessment of Pollution Related Corrosion Damage. F. H. Haynie. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 3-18. (Fe82-33)
13. Electrochemical Behavior of Atmospheric Pollutants in Thin Liquid Layers Related to Atmospheric Corrosion. C. Fiaud. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 161-166. (Ni82-7)
14. Electrotopygraphy - A New Tool for Corrosion Research. M. Ensanian. Extended Abstracts, International Symposium on Atmospheric Corrosion (October 5-10, 1980, Hollywood, Florida), Electrochemical Society, v. 80-2, 1980, pp. 480-482. (Fe82-36)
15. Evaluation of the Effects of Microclimate Differences on Corrosion. F. H. Haynie. Atmospheric Corrosion of Metals, edited by S. W. Dean, Jr., and E. C. Rhea, American Society for Testing and Materials, ASTM STP 767, 1982, pp. 286-308. (Fe82-39)
16. Indoor Atmospheric Corrosion of Copper, Silver, Nickel, Cobalt and Iron. D. W. Rice, R. J. Cappel, P. B. P. Phipps, and P. J. Peterson. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 651-666. (Cu82-21)
17. Stress Corrosion of Metals in the Atmosphere. A. Gallacio. Extended Abstracts, International Symposium on Atmospheric Corrosion (October 5-10, 1980, Hollywood, Florida), Electrochemical Society, v. 80-2, 1980, pp. 581-582. (Fe82-47)
18. Tarnishing of Silver by Organic Sulfur Vapors: Rates and Film Characteristics. J. D. Sinclair. J. Electrochem. Soc., v. 129, No. 1, 1982, pp. 33-40.

The rate of formation of tarnish films on silver coupons by vapors generated from organic sulfur compounds, especially dimethyldisulfide, has been measured at room temperature at both high and low relative humidity. The results for freshly cleaned silver coupons, as determined by cathodic reduction methods, indicate that atmospheres generated by organic sulfides rapidly tarnish silver. The rate increases with sulfur chain length and with the flux of u.v. light of wavelength greater than 2900Å. A mechanism involving the formation of free radicals is proposed. The tarnish composition is essentially identical to the sulfide films formed by hydrogen sulfide or by vapors from flowers of sulfur. Sulfide film morphology, as analyzed by SEM, tends to be more like field tarnished films than the highly structured tarnish films generated by flowers of sulfur vapor. Dimethyldisulfide has been used as a rapid, convenient life test gas for room temperature studies.

19. The Atmospheric Corrosion of Tin and Tin Alloys. M. E. Warwick and W. B. Hampshire. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 509-528. (Cu82-27)
20. The USAF Corrosion Testing Program and a Corrosion Severity Index Algorithm. R. Summitt and F. T. Fink. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 545-564. (Al82-31)
21. Theoretical and Engineering Principles of Atmospheric Corrosion of Metals. Y. N. Mikhailovskii. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 85-106. (Fe82-52)

1981

1. Atmospheric Corrosion of Copper and Silver. D. W. Rice, P. J. Peterson, E. B. Rigby, P. B. P. Phipps, R. J. Cappell, and R. Tremoureux. J. Electrochem. Soc., v. 128, No. 2, 1981, pp. 275-284. (Cu81-3)
2. Poland - The Most Polluted Country in the World. L. Timberlake. New Scientist, v. 92, No. 1276, October 22, 1981, pp. 248-250. (Fe81-11)
3. Protective Coatings for Silvered Reflectors in Solar Applications. S. M. Wong. Extended Abstracts, Fall Meeting, Electrochemical Society, Denver, Co., v. 81-2, October 11-16, 1981, p. 535.

Research on silvered reflectors is important for concentrator applications in solar energy conversion systems. Silver, generally deposited in thin layers onto a substrate, possesses the highest solar reflectance among all metals. However, a protective overcoat needs to be applied to the silver layer to prevent agglomeration, corrosion, degradation, delamination, etc., that leads to silver's ultimate loss of reflectance under environmental exposure.

The protective coatings selected for this study include sputtered chromium, copper, Hastelloy, Inconel-600, Inconel-700, molybdenum, stainless steel 304, titanium, wet chemically processed copper, and paint.

In this paper, data will be presented on the performance and time to failure of silvered mirrors with the above mentioned protective coatings after they have been subjected to accelerated tests which simulate stresses encountered in solar applications. These tests include salt spray, HCl vapor, and Weatherometer tests. The effects of salt, acid, relative humidity, temperature cycling, solar UV, pollutants, and mechanical stresses on the specimens are evaluated. In addition, dark field microscopy, SEM, and diffuse and specular reflectance measurements were used at different stages of the tests; the reflectance measurements were made using a He-Ne laser as well as a spectrophotometer. These measurements are used to correlate test results and help define the

relative merit of each test. Mechanisms of silver degradation and, hence, methods of its prevention will be discussed.

4. Resistance of Titanium to Atmospheric Corrosion. L. C. Covington and R. W. Shutz. Paper No. 113, Corrosion/81, Toronto, Canada, National Association of Corrosion Engineers, Houston, TX, April 6-10, 1981, 7 pp.

Ten different alloys of titanium were evaluated after 20 years exposure at five sites. Some of the specimens were discolored and covered with a heavy layer of dirt, but no evidence of corrosion of any significance was found.

1980

1. A Model of Atmospheric Corrosion of Metals Allowing for Meteorological and Aerochemical Characteristics. Y. N. Mikhailovikii, P. V. Strekalov and V. V. Agafonov. Protection of Metals, v. 16, No. 4, 1980, pp. 308-323. (Fe80-1)
2. A Review of Air Pollutant Damage to Materials. J. E. Yocum and A. R. Stankunas. Draft report to Environmental Criteria and Assessment Office, Office of Research and Development, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, December 1980, 92 pp. (Fe80-2)
3. Background and Principles of Long-Term Performance of Building Materials. S. E. Pihlajavaara. Durability of Building Materials and Components, ASTM STP 691, edited by P. J. Sereda and G. G. Litvan, American Society for Testing and Materials, 1980, pp. 5-16. (Fe80-4)
4. Corrosion of Metal in Wood Products. A. J. Baker. Durability of Building Materials and Components, ASTM STP 691, edited by P. J. Sereda and G. G. Litvan, 1980, pp. 981-993. (Fe80-7)
5. Critical Review of the Available Physicochemical Material Damage Functions of Air Pollution. M. Benarie. Report No. EUR-6643, Commission on the European Communities, 1980, 97 pp. (Fe80-8)
6. Durability of Some Common Building Materials. W. H. Gutt and L. H. Everett. Durability of Building Materials and Components, ASTM STP 691, edited by P. J. Sereda and G. G. Litvan, American Society for Testing and Materials, 1980, pp. 131-144. (Fe80-10)

7. Indoor Corrosion of Metals. D. W. Rice, R. J. Cappell, W. Kinsolving and J. J. Laskowski. J. Electrochem. Soc., v. 127, No. 4, 1980, pp. 891-901. (Fe80-11)
8. Pacer Line: An Environmental Corrosion Severity Classification System. R. Summitt and F. T. Fink. AFWAL-TR-80-4102 (Part I), Wright Aeronautical Laboratories, Wright-Patterson AFB, Ohio, August 1980, 121 pp. (Fe80-16)
9. Pacer Line: Experimental Determination of Environmental Corrosion Severity. R. Summitt and F. T. Fink. AFWAL-TR-80-4102 (Part 2), Wright Aeronautical Laboratories, Wright-Patterson AFB, Ohio, June 1980, 28 pp. (Fe80-17)
10. Regional Air Pollution Study: Effects of Airborne Sulfur Pollutants on Materials. F. Mansfeld. NTIS Report PB81-126351, January 1980, 163 pp. (Fe80-18)

1979

1. Atmospheric Corrosion of Cobalt. D. W. Rice, P. B. P. Phipps and R. Tremoureux. J. Electrochem. Soc., v. 126, No. 9, 1979, pp. 1459-1466.

Cobalt atmospheric corrosion is discussed, ranging from nucleation of water to observed indoor corrosion rates. The air-exposed surfaces of cobalt are shown to be complex oxyhydroxides. Significant quantities of water are adsorbed on this surface. The initial stage of corrosion in a polluted environment is shown to be very heterogeneous. Corrosion kinetics for cobalt are linear and are exponentially dependent on relative humidity. The partial pressures of SO_2 , Cl_2 and NH_3 significantly influence cobalt corrosion while H_2S , NO_2 , and O_3 show little effect. Cobalt corrodes in indoor environments at rates similar to nickel and follows log normal statistics over the field site population studied.

2. Results of 30 Months Atmospheric Corrosion Testing in St. Louis, MO, U.S.A. F. Mansfeld. Reliability of Materials for Solar Energy--Workshop Proceedings, CONF-781228, v. 2, Pt. 1, October 1979, pp. 627-657. (Fe79-7)
3. Statistical Assessment of the Effect of Fluctuations in the Atmospheric Concentration of Sulfur Dioxide on the Corrosion Rate of Metals. Yu. N. Mikhailovskii and V. A. San'ko. Zashch. Met., v. 15, No. 4, 1979, pp. 432-437 (Russian). (Fe79-8)

4. The Effect of Atmospheric Corrosion on the Reliability of Electronic Parts. B. Henzlik. Koroze Ochr. Mater., v. 5, 1979, pp. 90-91 (Czech). (Cu79-6)
5. Use of Building Surfaces in the Passive Abatement of Gaseous Air Pollutants. H. S. Judeikis. J. Architectural Research, v. 7, No. 1, March 1979, pp. 28-33. (Fe79-10)

1978

1. Adsorption of Sulfur Dioxide on Metals and Mechanism of Its Effect on Atmospheric Corrosion. Y. N. Mikhailovskii, P. V. Strekalov and T. S. Balandina. Zashch. Met., v. 14, No. 3, 1978, pp. 248-252 (Russian).

The kinetics of the mass changes on freshly formed cadmium and silver layers due to adsorption and corrosion of their surface by the gaseous SO_2 , water vapor, water vapor + SO_2 , and water vapor + SO_2 + SO_3 was studied experimentally by the piezoelectric quartz microweighing method at -30 to 20° . The amount of SO_2 adsorbed increased with increasing SO_2 partial pressure and decreasing temperature. In the early stage of the corrosion process, the SO_2 adsorbed in the thin H_2O layer does not affect the stability of the chemisorbed H_2O layer responsible for the metal passivity. The net increment to the metal mass due to the corrosion by H_2O + SO_2 mixture, after the vacuum desorption of the H_2O + SO_2 from the surface, is comparable to that caused by the treatment with pure H_2O vapor. If SO_3 is present in the gaseous medium to which the freshly formed metal surface is exposed, the irreversible increment to the metal mass rapidly increases and during the H_2O sorption-vacuum desorption cycles the amount of H_2O adsorbed steadily increases. This effect is not observed if SO_3 is absent. After the metal surface was once in contact with SO_3 , the secondarily adsorbed H_2O layers increase the rate of metal dissolution even if the contact with sulfur oxides was stopped and the increment to cadmium mass is by an order of magnitude higher than that in the atmosphere of SO_2 + H_2O . A catalytic oxidation of SO_2 on the partially oxidized metal surface is assumed. After the resulting $\text{SO}_3 \cdot n\text{H}_2\text{O}$ reaches a critical concentration, the formation begins of the SO_4^{2-} ions activating the metal surface. If only pure H_2O , or H_2O containing SO_2 , is adsorbed on the metal surface, the active centers are to some extent blocked and the corrosion process is inhibited. The presence of SO_3 then affects in a deciding way the rate of accumulation of the local active sulfate centers and thus the corrosion rate of cadmium.

2. ASTM Atmospheric Corrosion Testing: 1906 to 1976. W. H. Ailor. Atmospheric Factors Affecting the Corrosion of Engineering Metals, ASTM STP 646, edited by S. K. Coburn, American Society for Testing and Materials, 1978, pp. 129-151. (Fe78-2)

3. Atmospheric Corrosion. M. G. Fontana and N. D. Greene. Chapt. 8 in Corrosion Engineering, McGraw Hill Company, 2nd ed., 1978, pp. 265-268. (Fe78-3)
4. Atmospheric Corrosion. T. Hakkarainen. Tutkimus Tek., 1978, Nos. 4-5, pp. 46-54 (Finnish). (Fe78-4)
5. Atmospheric Laboratory Bench. Y. N. Mikhailovskii, V. A. San'ko, N. A. Sokolov and P. N. Kudryavtsev. Zashch. Met., v. 14, No. 4, 1978, pp. 515-517 (Russian). (Fe78-7)
6. Corrosion Investigations at Panama Canal Zone. M. A. Pelensky, J. J. Jaworski and A. Gallaccio. Atmospheric Factors Affecting the Corrosion of Engineering Metals, ASTM STP 646, edited by S. K. Coburn, American Society for Testing and Materials, 1978, pp. 58-73. (Fe78-9)
7. Deteriorative Effect of Sulfur Pollution on Materials. J. O. Nriagu. Chapt. 1 in Sulfur in the Environment, Part II: Ecological Impacts, edited by J. O. Nriagu, Wiley, New York, N.Y., 1978, pp. 1-59. (Fe78-11)
8. Effect of Daily Fluctuations of Humidity and Air Temperature on Moisture Sorption by a Metal Surface and on the Kinetics of Atmospheric Corrosion. P. V. Strekalov, Y. N. Mikhailovskii and M. V. Danilova. Zashch. Met., v. 14, No. 3, 1978, pp. 243-247 (Russian). (Al78-6)
9. Final Report on the ASTM Study: Atmospheric Galvanic Corrosion of Magnesium Coupled to Other Metals. A. Baboian. Atmospheric Factors Affecting the Corrosion of Engineering Metals, ASTM STP 646, edited by S. K. Coburn, American Society for Testing and Materials, 1978, pp. 17-29.

In 1949 a study was initiated by H. O. Teeple sponsored by Subcommittee VIII (Galvanic and Electrolytic Corrosion) of the American Society for Testing and Materials (ASTM) Committee B-3 (Corrosion of Nonferrous Metals and Alloys). This study covered the atmospheric galvanic corrosion of magnesium coupled to a number of dissimilar metals and alloys. Previously, results were reported for two and one half years exposure at State College and Kure Beach. This report, sponsored by Subcommittee VII (Galvanic Corrosion) of ASTM Committee G-1 (Corrosion of Metals), presents the final data from this study after an approximate 22-year exposure at these test sites.
10. Metal Corrosion Due to Sulfur Dioxide Effect. S. Filz. VDI Ber., v. 314, 1978, pp. 103-107 (German).

The relation between metal corrosion and SO_2 content of air, critical humidity, corrosion mechanism, corrosion rates of various metals, effect of dust, and critical SO_2 concentration are discussed.

11. Studies of Lead 15 wt% Tin Alloy Corrosion in an Industrial Environment. J. S. Bullock. Report No. Y2132, Oak Ridge Y-12 plant, Oak Ridge, TN (USA), October 1978, 28 pp.

The corrosion properties of a lead-15 wt-pct tin alloy in aqueous solutions having a pH from 2 to 6 were studied as a function of contamination by sulfur dioxide, chloride ion, fluoride ion, and carbon dioxide. Electrochemical methods were used. Higher acidity caused higher corrosion rates. Sulfur dioxide and carbon dioxide were found to inhibit corrosion, the chloride ion to have a mild aggressive effect, and the fluoride ion to have a noticeable aggressive effect. Semiquantitative estimates of the effects were made.

12. The Corrosion and Protection of Metals in the Buildings and Construction Industries. B. G. Callaghan. J. Oil Color Chemists Assoc., v. 61, No. 11, November 1978, pp. 411-418. (Fe78-17)

1977

1. Effects of Sulphur Dioxide on Materials. S. K. Gajendragadkar. Chem. Age India, v. 28, No. 8, 1977, pp. 673-677. (Fe77-5)
2. Effects of the Environment. G. Thomson. Conservation in Australia, 1977, pp. 46-53.

The effects of ultra-violet radiation, humidity and air pollution on the deterioration of materials is discussed with particular reference to the Australian environment.

3. Effects on Economic Materials and Structures. J. E. Yocum and J. B. Upham. Chapt. 2 in Air Pollution, edited by A. C. Stern, Academic Press, New York, N.Y., v. 2, 1977, pp. 65-116. (Fe77-6)
4. Estimation of Pollutants Concentration in Atmosphere by Measuring Corrosion Rates of Several Metals. II. Correlation Between Reflectances of Exposed Metals and Deterioration of Exposed Rubber. G. Takao, and M. Masakasu. Taiki Osen Kenkyu, v. 11, No. 6, 1977, pp. 452-455 (Japanese). (Cu77-2)
5. Galvanic Corrosion IN the Atmosphere. V. Kucera. Rapp.-Korrosionsinst., No. 16, 1977, 43 pp. (Swedish). (Fe77-9)

6. Nitrogen Oxides. National Research Council Staff. Environmental Effects Research series, Contract EPA-68-02-1226, National Research Council, Washington, D.C., February 1977, 503 pp.

This report is a review of current knowledge of the environmental health basis for control of manmade sources of nitrogen oxide emissions. The literature review covered the period through 1974. The principal subject areas considered in the report include: sources and control of atmospheric nitrogen oxides; analytical methodology; concentrations and chemical reactions in the atmosphere; and the effects of nitrogen oxides on human health, materials, vegetation, light transmission, and natural ecosystems. Emphasis is primarily on nitric oxide (NO) and nitrogen dioxide (NO₂), designated by the composite formula NO_x for nitrogen oxides. The major manmade source is the combustion of fossil fuel. Highest atmospheric concentrations are found in heavily populated, industrialized urban areas. Both acute and chronic health effects resulting from short-term and long-term exposures, are discussed in the report. Effects range from slight increases in airway resistance to death depending upon exposure concentrations.

7. Pollution and the Deterioration of Materials. S. H. H. Chaston. Conversation in Australia, 1977, pp. 54-59.

The atmospheric pollutants that cause the deterioration of materials are considered under three main headings: (i) air pollutants; (ii) oxidants associated with photochemical smog, and (iii) airborne particles. The sources of these pollutants and the damage they cause to materials are discussed.

1976

1. Acid Precipitation. G. E. Likens. Chem. Eng. News, v. 54, No. 48, November 22, 1976, pp. 29-44. (Fe76-1)
2. Air Pollutants and Possible Effects on Artistic and Archaeological Materials. F. Guidobaldi. Conservazione dei Monumenti, 1976, pp. 14-48 (Italian).

Data on chemical compounds present in polluted air are reported and the possible effects on artistic and archaeological materials are discussed. Details are given on the effects of acid rain, carbon dioxide and sulfur oxides. Principal sources of pollution and pollutants emitted by different sources are also summarized.

3. Air Pollution Damage Functions. A. Hershaft. Environmental Science and Technology, v. 10, No. 10, October 1976, pp. 992-995. (Zn76-1)

4. Conservation of Monuments. Proceedings of the 2nd Session of the 29th National Congress of the Assoc. Termotecnica Italiana, Florence (September 25-27, 1974), Antonio Barbieri, Viale Premuda 2, Milano, 1976, 252 pp. (Italian).

Papers are collected in five sections: atmospheric pollution and climate, stone, metal, mural and panel paintings, glass, wood and textiles.

5. Corrosion of Light Metals and Their Alloys in an Atmosphere Polluted With Sulfur Dioxide and With Products of Its Neutralization With Ammonia. B. Mazurkiewicz, J. Banas, K. Bieda and A. Piotrowski. Zesz. Nauk. Akad. Gorn.-Hutn. im. Stanislaw Staszica, Mat. Fiz. Chem., v. 27, 1976, pp. 115-126 (Polish). (Al76-3)
6. Corrosion of Metals in Tropical Environments: Final Report of 16-Year Exposures. C. R. Southwell. Materials Performance, v. 15, No. 7, July 1976, pp. 9-25.

The results of 16-year corrosion tests performed by the Naval Research Laboratory, Washington, D.C., on 52 metals and alloys in tropical seawater and freshwater environments are presented.

7. Effects of Power Plant Emissions on Materials. J. E. Yocom and N. Grappone. Research Corporation of New England, Wethersfield, Connecticut, NTIS Report PB-257539, July 1976, 85 pp. (Fe76-6)
8. Fundamentals of Atmospheric Corrosion. G. Oelsner and W. Hoepfner. Werkst. Korros., v. 27, No. 5, 1976, p. 354.

Fundamentals of atmospheric corrosion and the effects of carbon dioxide, sulfur dioxide, hydrogen sulfide, particulates, and chlorinated and ammoniated compounds on construction materials are discussed.

9. How Environmental Pollutants Diminish Contact Reliability. C. A. Russell. Insulation/Circuits, v. 22, No. 10, 1976, pp. 43-46. (Cu76-5)
10. Initial Stages of Atmospheric Corrosion of Metals in Humid Air Above and Below the Freezing Point. Y. N. Mikhailovskii, P. V. Strekalov and T. S. Balandina. Zashch. Met., v. 12, No. 5, 1976, pp. 513-518 (Russian). (Zn76-5)
11. Material Changes by Ozone. U. Arndt and H. Ross. VDI-Ber., v. 270, 1976, pp. 197-210 (German).*

Alteration of materials such as rubbers, dyes, and metals by ozone is reviewed.

12. Methods for the Determination of Corrosion Losses. M. Kulis. Ochr. Koroz., v. 19, No. 9, France 1976, pp. 235-237 (Polish). (Fe76-12)
13. Outdoor Weathering: Its Objectives and Limits. F. Rosendahl. Proc. 13th FATIPEC Congress, Cannes, France, 1976, pp. 563-567 (German).

Difficulties in assessing outdoor weathering results, for example, to check the performance of artificial weathering cycles, are discussed. A particular problem is the alternation of active and inactive weathering periods, which distorts the time scale. Statistical procedures for designing exposure test series and evaluating the results should be applied.

14. Patination of Lead. An Infra-red Spectroscopic Study. G. C. Tranter. British Corrosion Journal, v. 11, No. 4, 1976, pp. 222-224.

This paper reports an examination by infrared spectroscopy of the corrosion products from lead sheets exposed under test conditions and from lead cladding in rural and urban buildings up to an age of 129 years. The results indicate that on weathering a progressively more resistant film of corrosion products is formed, the sequence reflecting the relative atmospheric abundance and acidity of carbon dioxide, sulfur dioxide and sulfur trioxide. Thus, the corrosion product formation is observed to be basic lead carbonate production followed by normal lead sulfite and normal lead sulfate. The formation of orthorhombic lead monoxide was observed and it is suggested that this may be a precursor of basic lead carbonate.

15. Possibilities for the Determination of Electrolyte Formation on Surfaces by Condensation and Moisture Particle Impact. I. Kokoska and J. Prusek. Werkst. Korros., v. 27, No. 1, 1976, pp. 16-20 (German).

To control the presence of electrolyte films on metal surfaces, measuring probes (or sensors) are attached to the object to be studied, and the change of the electric resistance of the probes is measured. These probes are passive dipoles and form a system of metallic area electrodes separated from each other by a crevice of defined dimensions (geometrical shape and size are adjusted to the particular problem). The electrodes are applied to a support combining high insulation resistance, water resistance, low weight, and good thermal conductivity. The probes are connected to an electronic system recording the signals from the individual probes, so that the duration and the frequency of moisture film formation can be determined. The recording strip also differentiates between condensation (dew formation) and direct impact of liquid particles.

16. Protecting Electronics From Atmospheric Corrosion. D. V. Couden. Materials Engineering, May 1976, pp. 22-25. (Cu76-7)

17. Protection Against Atmospheric Corrosion. K. Barton. Translated by J. R. Duncan, Wiley, New York, N.Y., 1976, 194 pp. (Fe76-14)

18. Protection by Cleaning and Conservation. J. Riederer. Das Gebaudereiniger-Handwerk, No. 2, 1976, pp. 14-15 (German).

One of the main reasons for the decay of monuments and sculptures in the open is poor maintenance. A regular removal of dirt and soot as well as water repellent treatment would prevent the attack of most of the destructive agents of stone as well as on metals and glass.

19. Replacement of Steel Connectors by Titanium Alloy. S. Angelides. Chapter in The Acropolis, Hellenic Republic, Ministry of Culture and Science, Athens, Greece, 1976, pp. 95-96.

The proposal for the Portico of the Erechtheion consists of dismantling it, transferring the Caryatid statues indoors, and replacing all steel parts with titanium alloys. One of the advantages of using titanium is that its thermal expansion factor is approximately the same as that of marble. The replacement of the steel beam over the heads of the Caryatid statues with a titanium beam is proposed to obtain minimal flexibility since the overlying architrave is weak. A life-size model of the Portico has been constructed in order to determine the deflections in the proposed reinforced structure and to train personnel for the dismantling of the Portico. The plan of action for the Portico is reversible; once the air pollution has been controlled, the Caryatid statues may be returned to their original places on the monument.

20. Use of Computing-Decision Devices for the Construction of Statistical Models for Interpretation of the Atmospheric Corrosion of Metals. Y. N. Mikhailovskii, E. I. Sergeeva, V. A. San'ko and V. V. Agafonov. Prot. Met., v. 12, No. 1, January-February 1976, pp. 102-105.

The complex dependence of the rate of atmospheric corrosion on meteorological factors which vary in time with a daily or seasonable periodicity hinders an accurate prediction of the corrosion of metals in different climatic regions. The calculation of the expected corrosion from averaged values of the meteorological parameters using the method of correlation analysis can be regarded as a first approximation. More rigorous is the method of taking account of statistical data on the meteorological factors characterizing the climate of a given zone, above all obtained from multiyear observations of the repeatability of the values of the moisture content of the air (or the presence of a phase film of moisture on the surface of the metal) in discrete temperature intervals. The statistical data on the corrosion of the base metals under adsorbed and phase layers of moisture at different temperatures, calculated by this method, are used for regionalizing the corrosion aggressiveness of the atmosphere in different climatic zones of the USSR.

1975

1. Air Pollution and Possible Effects on Archaeological Objects Buried in the Ground. B. Ottar and S. E. Haagenrud. Conservation in Archaeology and the Applied Arts, IIC, Stockholm Congress, 1975, pp. 199-206.

Information is needed concerning the emission, the atmospheric dispersion, and the deposition of the pollutants in the various geographical areas. Further, one has to identify the aggressive chemical components which may possibly be present in sufficient amounts to have an effect on the archaeological samples. Finally, the extent of such effects will depend on the type of specimens and how deep in the ground and in what type of soil they are buried.

2. Bimetallic Corrosion Effects on Mild Steel in Natural Environments. K. E. Johnson and J. S. Abbott. NTIS Report PB-243665, 1975, 17 pp. (Fe75-3)
3. Conservation--The Regional Climate and Natural Conditions. O. P. Agrawal. Museum, v. 27, No. 4, 1975, pp. 161-165.

The tropical climatic conditions prevailing in South and Southeast Asia are extreme. Temperature and relative humidity in countries like Bangladesh, Sri Lanka, Burma, Thailand, Indonesia and Malaysia are very high throughout the year. Western parts of India, Afghanistan and Iran have a dry climate. In most parts of India, there is the monsoon type of climate, that is, alternating dry and wet seasons. Such conditions accelerate the damage caused to cultural property.

Light which is very intense in the tropical countries is another factor. Danger due to atmospheric pollution is increasing because of rapid industrialization. Most countries in this part cannot afford to have air-condition buildings for their museums. Research programs are needed which can solve some of these special problems.

4. Corrosion of Coated Metals. 5. Corrosion Testing. J. B. Mohler. Met. Finishing, v. 73, No. 8, 1975, pp. 48-50.

Methods for the evaluation of corrosion in outdoor exposures, immersion in water or water vapor, and salt spray are discussed.

5. Effects of Graphite Epoxy Composite Materials on the Corrosion Behavior of Aircraft Alloys. P. Fischer and J. DeLuccia. Naval Air Development Center, Warminster, PA, Vehicle Technology Dept. Report No. NADC-75031-30, April 1975, 36 pp. (A175-2)
6. Environmental Exposure System for Studying Air Pollution Damage to Materials. J. W. Spence, F. D. Stump, F. H. Haynie, and J. B. Upham. NTIS Report PB-240615, 1975, 46 pp. (Fe75-11)

7. Metal Protection by Vapor Phase Inhibitors. B. A. Miksic. Anti-Corros. Methods Mater., v. 22, No. 3, 1975, pp. 5-8.

The use of vapor phase inhibitors to reduce atmospheric corrosion of metallic structures is discussed. Vapor phase inhibitors obtain the same preventative effect as conventional methods by the simple introduction of the inhibitor device into the metal enclosure. Vapor phase inhibitors also provide positive protection under conditions where traditional coatings, wraps, and silica gel fail or cannot be used. Successful applications of vapor phase inhibitors include high humidity environments, marine environments with high salt concentrations, and industrial environments with sulfur dioxide levels ranging up to 0.15 wt pct.

8. Sulfates and the Environment-A Review. R. S. Greeley, R. P. Ouellette, J. T. Stone and S. Wilcox. Mitre Corp., McLean, Va., Report No. MTR-6895, March 1975, 155 pp.

This report has been prepared to review existing information on sulfates and their environmental effects. It covers the following topics: Origin and amounts of sulfates in the atmosphere (Sulfur flow through the ecosystem, Reactivity of sulfur compounds in the atmosphere, Fallout of sulfates, Emission sources); Atmospheric concentrations (Global concentrations, Sulfur concentrations over the United States, Relationship of sulfur dioxide to sulfates, Point source averages, Transport of sulfur dioxide in plumes, Acid rain, Concentrations due to mobile sources); Effects of sulfates (Human health effects of sulfates in the ambient air, Effects on animals, Effects on vegetation, Material effects, Standards); Measurement techniques (Filtering methods, Method for differentiating between sulfuric acid and sulfate salts, Direct methods for sulfuric acid in ambient air); Control technology (Naturally low sulfur fuels, Fuel desulfurization, Flue gas desulfurization, Sulfur dioxide control with tall stacks and/or intermittent control systems); Economics; and Status or regulations.

9. Sulfur Dioxide and Material Damage. D. G. Gillette. J. Air Pollution Control Association, v. 25, No. 12, December 1975, pp. 1238-1243. (Fe75-17)
10. The Outdoor Corrosion Performance of Plated ABS Plastics. V. E. Carter. Trans. Inst. Metal Finishing, Spring/Conf., v. 53, No. 1, 1975, pp. 61-64. (Cu75-6)
11. Universal Accelerated Weathering Cabinet for Weathering Tests of Metals and Protective Coatings. D. Knotkova-Cermakova, J. Kosobud, J. Vlckova and J. Honzak. Werkst. Korros., v. 26, No. 2, 1975, pp. 118-123 (German).

The development and construction features of a cabinet testing the atmospheric corrosion of metals and many kinds of protective coatings are discussed. The vertical cylindrical vessel is made of glass and has a

removable cover. On the bottom of the vessel is a smaller cylinder, the test vessel, with a perforated mantle through which the air with known humidity and impurity content is fed. A platinum wire attached to an arm of an analytical balance passes through a hole in the cover. A specimen-holding cage is fastened to the end of the wire. Two opposite openings are provided in the test vessel for spraying onto both sides of the specimen. The systems for preparing the contaminated air (sulfur dioxide) with known humidity and aerosol spraying are described.

1974

1. Air Pollution Effects on Catastrophic Failure of Metals. J. Gerhard and F. H. Haynie. Environmental Protection Agency, EPA-650/3-74-009, November 1974, 33 pp. (Fe74-2)
2. An Evaluation of Titanium Panels After Seven Years' Exposure in a Marine Atmosphere. L. C. Covington. Corrosion in Natural Environments, ASTM STP 558, American Society for Testing and Materials, 1974, pp. 97-98.

An evaluation was made of test panels of four titanium alloys that were exposed to a marine atmosphere for seven years at Point Reyes, California, as part of the ASTM B-3V1 1957 test program. No evidence of corrosion or significant change in physical properties was found. It was concluded that titanium is virtually immune to corrosion under most atmospheric exposure conditions.

3. Atmospheric Corrosion. H. Laub. Galvanotechnik, v. 65, No. 3, 1974, pp. 209-221 (German).

The basic causes of atmospheric corrosion, its electrochemical aspects, factors which influence it, its evaluation, and the difficulty of predicting such corrosion are reviewed.

4. Corrosion Aggressivity of Model Regions of Czechoslovakia. D. Knotkova-Cermakova, B. Bosek and J. Vlckova. Corrosion in Natural Environments, ASTM STP 558, American Society for Testing and Materials, 1974, pp. 52-74. (Fe74-8)
5. Corrosion of Metals in the Atmosphere. W. K. Boyd and F. W. Fink. MCIC-74-23, Battelle-Columbus Labs., Metals and Ceramics Information Center, Columbus, Ohio, August 1974, 77 pp. (Fe74-9)
6. Design of a Laboratory Experiment to Identify the Effects of Environmental Pollutants on Materials. J. W. Spence and F. H. Haynie. Corrosion in Natural Environments, ASTM STP 558, American Society for Testing and Materials, 1974, pp. 279-291. (Fe74-10)

7. Effect of Air Pollution on Materials and Technical Equipment. D. Knotkova-Cermakova, K. Barton and B. Dolezel. Ochr. Ovzduš., v. 6, No. 6, June 1974, pp. 75-83 (Czech). (Fe74-12)
8. Environment and Quality of Life. Literature Study on the Economic Consequences of the Damages and Annoyances Both in Materials and Vegetation and in Men and Animals Caused by Sulfur Dioxide Air Pollution. E. Lahmann. Commission of the European Communities, Luxembourg, September 1974, 150 pp. (German). (Fe74-16)
9. Factors Affecting the Adsorption of Atmospheric SO₂ on to Lead Surfaces. J. R. Duncan and D. J. Spedding. Corros. Sci., v. 14, No. 10, 1974, pp. 607-610.

The mean velocity of deposition (the mass of sulfur dioxide adsorbed per unit area divided by the mean atmospheric sulfur dioxide concentration times the time of exposure) of sulfur dioxide on lead foil, in a relative humidity range of 45 to 99 percent, was quite small (0.14 to 0.28 mm/sec) and varied widely from sample to sample. The relative humidity and the sulfur dioxide concentration had no effect on the velocity of deposition. No desorption was observed upon exposure to air free of sulfur dioxide. The results support the conclusion that sulfur dioxide adsorption occurs upon specific sites, probably involving surface oxide or hydroxide. In this case the dark spots of high adsorptivity observed upon some samples may be lead (IV) dioxide.

10. Petroleum and the Environment, Rome - EUR (April 11-14). Poligrafico Artioli Editore, Modena, Italy, 1974.

The publication concerns topics discussed at the third international congress on petroleum. Both the negative and the positive aspects of the production of petroleum derivatives are described and much documentation is given.

Contents include: "Use of petroleum-based products in conservation of works of art," by A. E. Werner, and "Action of sulfur dioxide and some other pollutants on works of art," by G. Thomson. Other articles consider stone deterioration and microscopy.

11. Rapid Electrochemical Procedure to Measure the Atmospheric Corrosion Resistance. E. Erdos. Galvano-Organo, No. 443, April 1974, pp. 382-385 (French). (Cu74-7)
12. Seven-Year Exposure at Point Reyes, California. W. H. Ailor. Corrosion in Natural Environments, ASTM STP 558, American Society for Testing and Materials, 1974, pp. 75-81. (A174-6)
13. The Economic Damages of Air Pollution. T. E. Waddell. NTIS Report PB-235701, 1974, 156 pp. (Fe74-21)

14. The Economics of Clean Air in Perspective. F. H. Haynie. Materials Prot. and Perf., v. 13, No. 4, April 1974, pp. 33-38. (Fe74-22)
15. The Environment and Collections. G. W. Rogers. Canadian Conservation Institute Newsletter, No. 4, August 1974, pp. 5-6.

The influence of moisture, temperature, light and air pollutants on works of art are discussed. The author states that environmental factors can be divided into three types: gases, such as sulfur oxides, hydrogen sulfide, nitrogen oxides, ammonia and ozone; aerosols, in the form of suspensions in air of acidic droplets; and dirt usually coated with tarry organic material.

16. The Environment and Collections (Part 2). G. W. Rogers. Canadian Conservation Institute Newsletter, No. 5, November 1974, pp. 2-3.

Pollutants that concern the museum world are divided into two types: gases (for example, SO_2 , H_2S , NO_x , NH_3 , O_3), and aerosols (suspensions in air of acidic droplets) and dirt, usually coated with tarry organic materials. Sulfur compounds are the most damaging; they can be converted to sulphuric acid which can destroy the basic structure of materials like paper, textiles, wood. Corrosion of most alloys has been found to be almost linear with SO_2 concentration in a 10-year study done across Canada. The best method of dealing with these pollutants is their removal at the source.

17. The Use of Weather and Climatological Data in Evaluating the Durability of Building Components and Materials. L. W. Masters and C. W. Wolfe. NTIS Report COM-74-50841/7, August 1974, 102 pp. (Fe74-25)
18. Weather Factors Affecting Corrosion of Metals. P. J. Sereda. Corrosion in Natural Environments, ASTM STP 558, American Society for Testing and Materials, 1974, pp. 7-22. (Fe74-27)

1973

1. Air Pollution: Air Quality Criteria for Nitrogen Oxides. NATO Committee on the Challenges of Modern Society, Brussels, Belgium. Report No. NATO/CCMS-15, January 1973, 231 pp.

This report discusses: Properties of nitrogen oxides and physical effects on light transmission; Sources and control of atmospheric nitrogen oxides; Methods for measurement of nitrogen oxides; Atmospheric levels of nitrogen oxides; Chemical interactions of nitrogen oxides in the atmosphere; Effects of nitrogen oxides on materials; Effects of nitrogen oxides on vegetation; Toxicological effects of nitrogen oxides; Epidemiological appraisal of nitrogen oxides.

2. Concentrations, Decay Rates, and Removal of Ozone and Their Relation to Establishing Clean Indoor Air. R. H. Sabersky, D. A. Sinema and F. H. Shair. Environ. Sci. Technol., v. 7, No. 4, 1973, pp. 347-353.

Transitory concentrations of ozone within typical buildings located in photochemical smoggy areas, were found to lag in time and to be only a little less in value as compared to corresponding outdoor concentrations. The ozone decomposition within buildings involved a heterogeneous mechanism. Decomposition rate constants for several common surfaces were found to range in value from approximately 10^{-1} to 10^{-3} $\text{ft}^3/\text{ft}^2\text{-min}$. Rubber, fabrics, and plastics appeared to decompose ozone much more rapidly than metals and glass. All materials demonstrated a reduction in the rate constant in extended use. One material, plywood, showed some recovery after a 2-day exposure to an ozone-free atmosphere. Experiments indicated that certain filters, especially activated charcoal, can be used to reduce indoor levels of ozone well below the maximum acceptable limits. Calculations, based upon a "stirred-tank" reactor model, yielded results similar to those observed with respect to transitory indoor versus outdoor concentrations of ozone.

3. Corrosion Caused by Perspiration. G. A. Tret'yakova and V. P. Barannik. Zashch. Metal, v. 9, No. 6, November-December 1973, pp. 715-715 (Russian). (Fe73-9)
4. Economic Effects of Air Pollution on Electrical Contacts. R. C. Robbins. Holm Seminar on Electrical Contact Phenomena, 19th Annual Proceedings, Illinois Inst. of Technology, Chicago, Ill., October 15-18, 1973, pp. 80-85. (Cu73-2)
5. Investigation of Damages (On Cultural Properties) Caused by Air Pollution. T. Kadokura. Science for Conservation, No. 11, 1973, pp. 69-85 (Japanese).

A detailed questionnaire was sent to fifty-two museums in Japan to investigate the effects of air pollution on the museum objects exhibited inside and outside museums. Out of forty responses, damages were reported for nine objects and eight buildings.

6. The Damaging Effects of Air Pollution on Works of Art. J. Riederer. Proc. 3rd Int. Union Air Pollut. Prev. Assoc. - VDI-Komm. Reinhaltung Luft Int. Clean Air Congr. (Duesseldorf, October 8-12, 1973), 1973, pp. A86-A89 (German). (Cu73-3)
7. The Role of Coatings in Corrosion Prevention. Future Trends. V. Ashworth and R. P. M. Procter. Journal of the Oil and Colour Chemists Association, v. 56, No. 10, October 1973, pp. 478-489. (Fe73-24)

1972

1. Phase Composition and Thermal Stability of Products From Atmospheric Corrosion of Lead. I. A. Efimov, B. N. Rybakov, G. V. Maslova and U. Y. Kharitonov. *Zashch. Metal.*, v. 8, No. 6, 1972, pp. 711-712 (Russian).

Specimens of lead of grade SO according to GOST 3778-65, obtained by semicontinuous casting, were subjected to natural corrosion tests. The climatic conditions of the tests were evaluated according to the duration of the wetting of the metal surface, which amounted to 1,700, 1,250, and 2,000 hr/year for regions A, B, and C, respectively. The atmosphere was contaminated with sulfur dioxide, the concentration of which was measured by a linear-coloristic method. The average sulfur dioxide content of regions A and B amounted to 0.25 and 0.13 mg/m², respectively; in region C, there were traces of sulfur dioxide (with relative fluctuations of 10 to 20 percent). The phase composition and thermal stability of the powdery corrosion products was determined two years after the beginning of the tests. The composition and proportions of the components were determined by X-ray diffraction and infrared spectroscopy and refined thermographically on the Kurnakov pyrometer designed at the Institute of General and Organic Chemistry, Academy of Sciences of the USSR. The content of products subjected to thermal decomposition was determined from the loss in weight at the corresponding temperature effects, and the PbO content was determined by difference. The results from spectral and X-ray analysis and the temperature effects on the thermograms agree well with each other and with the published data for basic lead carbonates and sulfates.

2. Reactions of Sulfur Dioxide With Adsorbed Layers of Moisture Under Conditions of Atmospheric Corrosion of Metals. P. V. Strekalov, Yu. N. Mikhailovskii. *Zashch. Metal.*, v. 8, No. 5, 1972, pp. 573-576 (Russian). (Fe72-16)
3. Survey on the Metal Corrosion by Air Pollution: Effect of Glauber's Salt on Metals. T. Nagano, A. Hattori, T. Nagai, Y. Ukishima, Y. Nakai, and I. Iwasaki. *Shizuoka-ken Eisei Kenkyusho Nenpo*, No. 16, 1972, pp. 217-226 (Japanese). (Fe72-18)

1971

1. A Survey and Economic Assessment of the Effect of Air Pollutants on Electrical Components. ITT Electrophysis Laboratory, Columbia, MD, NTIS Report PB-204183, August 1971, 89 pp. (Cu71-1)
2. Air Pollution by Sulfur Dioxides. Staff Report. National Industrial Pollution Control Council, Washington, D.C., February 1971, 27 pp. (Fe71-2)

3. Air Quality Criteria for Nitrogen Oxides. Environmental Protection Agency, Washington, D.C., Air Pollution Control Office. Report NAPCA-Pub-Ap-84, January 1971, 181 pp.

This publication reviews the chemical and physical characteristics of the nitrogen oxides and considers the relative merit of various analytical methods for measuring them in the atmosphere. It also discusses their effect on visibility, vegetation, and materials; their toxicological effects on animals and on man; and epidemiological studies that assess the general population dose response and the specific response of children to nitrogen oxides.

4. Atmospheric Corrosion of Silver. J. A. Lorenzen. Inst. Environ. Sci., Proc. 17th Annual Tech. Meet., Living in Our Environment, Los Angeles, California, April 26-30, 1971, pp. 110-116.**

The corrosion of silver in hydrogen sulfide, chlorine, and sulfur dioxide atmospheres has been studied, and the effects of the important environmental factors are now known. By understanding the process, one can design to control or inhibit corrosion. The results can also be used for accelerated testing of silver compounds.

5. Calculation of the Rate of Atmospheric Corrosion of Zinc and Cadmium Coatings in Various Climatic Regions. Y. N. Mikhailovskii, G. B. Klark, L. A. Shuvakhina, A. P. San'ko, Y. P. Gladkikh and V. V. Agafonov. Zashch. Metal., v. 7, No. 5, 1971, pp. 534-539 (Russian). (Zn71-4)
6. Corrosion Induced by SO₂ Under Controlled Conditions. B. Heimler, T. Sydberger, N. Vannerberg. Chapt. 27 in Proc. 6th Scandinavian Corrosion Congr., (Gothenburg, May 24-27, 1971), 1971, 13 pp. (Fe71-9)
7. Deterioration of Electrical Equipment in Adverse Environments. M. Rychtera. Daniel Davay & Co., Inc., 946 Asylum Ave., Hartford, Conn., January 1971, 190 pp.

A revised version of a book first published in Czech. The influence of the atmosphere on the performance and durability of a wide variety of materials used for electrical equipment is described. The author bases many of his criteria on statistical data accumulated from a number of test sites, especially in the tropics, where electrical materials have been exposed for periods of years to a wide range of atmospheres and conditions. Numerous test data are reported also based on laboratory experiments. The book is divided into four parts: analysis of climatic action, classification, modeling, and prognosis. The first of these considers the interrelationships of such factors as temperature and its fluctuations, relative and absolute humidities, sunlight, air circulation and bacterial attack. He proposes criteria of criticality and alternation against effects of the various destructive elements in the atmosphere. In part two, he establishes criteria of classification of climatic action so that topographic maps may be constructed depicting favorable and

unfavorable regions with respect to the criteria. These are used in tables which propose to permit prediction of probable atmospheric attack. In part 3, he conth respect to the criteria. These are used in tables which propose to permit prediction of probable atmospheric attack. In part 3, he constructs models of climatic action involving consideration of atmospheric tests, complex and simple climatic models, indirect testing and laboratory tests. Part 4 defines a method of predicting probable attack which involves establishing a numerical gradient depicting danger degrees. These degrees are then applied to rate probabilities of deterioration through excessive cooling, temperature variations, heat aging, water absorption and desorption, corrosion, photochemical action, microbial action, dust, rain and thunderstorms. Using these factors, tables of probabilities are presented covering the continents of Africa, Australia, new Zealand and Indonesia, Europe and Asia, North and South America. Located zones are by coordinate grid system of the areas covered. These is a subject and geographical index, numerous tabular and graphed data as well as black and white and colored figures showing various aspects of materials discussed in the book. References are substantially from Communist bloc sources, but are indicative of the vast accumulation of data on which the book is based.

8. How Materials Stand Up to Corrosion and Chemical Attack. R. J. Fabian and J. A. Vaccari. Mater. Eng., v. 73, No. 2, 1971, pp. 36-59.

A review is given of the corrosion resistance to waters, acids, bases and salts, solvents and cleaners, oils, fuels, petrochemical fluids, conventional chemicals, and to the atmosphere of construction materials.

9. Metal Coatings on Steel at Lighthouse Beach, Lagos. J. F. Stanners. Brit. Corrosion J., v. 6, No. 5, Sept. 1971, pp. 211-215. (Fe71-17)
10. Method for Investigating the Effect of Climatic Parameters on the Rate of Atmospheric Corrosion of Metals. Y. N. Mikhailovskii, L. A. Shuvalkhina, G. B. Klark and V. V. Agafonov. Protection of Metals, v. 7, 1971, p. 125.

The authors propose a method for the continuous recording of the rate of atmospheric corrosion of metals. It is based on the measurement of the electric resistnace of a thin metal layer (a vacuum condensate or a thin foil) during the corrosion process.

11. Present Status and Prospects on Air Pollution. U. Bardelli. Ingegneria, v. 5, 1971, pp. 311-316. (Fe71-19)
12. Role of Sulfur Dioxide in Atmospheric Corrosion. D. J. Spedding. Chem. Ind. N.Z., v. 6, 1971, pp. 39-41. (Fe71-20)

13. Technical-Economic Evaluation of Air-Pollution Corrosion Costs on Metals in the U.S. F. W. Fink, F. H. Buttner and W. K. Boyd. NTIS Report PB-198453, February 19, 1971, 160 pp. (Fe71-25)
14. The Corrosion of Copper, Tin, and Their Alloys. H. Leidheiser, Jr. Chapter 12, J. Wiley, New York, N.Y., 1971, pp. 261-273.

Pure tin has excellent resistance to corrosion in most environments. However, alloys of tin tend to have slightly less resistance than pure tin. Also, if care is not taken in electroplating tin to steel, failures can occur rather rapidly. Corrosion data for tin and some of its alloys are reported for various locations around the world.

1970

1. Corrosion Behavior of the Major Architectural and Structural Metals in Canadian Atmospheres. Summary of Ten-Year Results of Group I. E. V. Gibbons. Nat. Res. Council Can., Div. Bldg. Res., Tech. Pap. No. 328, 1970, 21 pp. (Fe70-5)
2. Design and Monitoring of Multiple and Varying Pollutant Concentration. E. Bassett, H. Frankel and R. Grenley. Preprint (Presented at the American Chemical Society Meeting, Division of Water, Air and Waste Chemistry, Chicago, Ill., September 13-18, 1970), Div. of Water, Air and Waste Chemistry, American Chemical Society, Washington, D.C., 1970, pp. 93-98. (Cu70-5)
3. Importance of Air Pollution in the Corrosion of Stone and Metals. E. M. Winkler. Eng. Geol., v. 4, No. 4, October 1970, pp. 327-334.

Evidence is presented that the ionic increase almost doubled in the Great Lakes-St. Lawrence River drainage basin, whereby about 20 to 50 percent of the ions are contributed from polluted atmospheres surrounding the lakes. Study indicated that improvement of automotive combustion will eliminate toxic CO and smog-producing unburned hydrocarbons, but will augment CO₂ and NO₂ to such a high level that the corrosion of stone and metals will increase rapidly.

4. Inquiry Into the Economic Effects of Air Pollution on Electrical Contacts. R. C. Robbins. SRI Project PSU-7345, Final Report, Stanford Research Institute, April 1970, 39 pp. (Al70-4)
5. Interstate Surveillance Network - 1969 Data. Division of Air Quality and Emission Data. Report NAPCA/APTD 70-3, U.S. Department of Health, Education, and Welfare, May 1970, 203 pp.

Raw data are tabulated on air pollution effects on materials at 274 stations throughout the United States and in Ontario, Canada, for calendar year 1969. The tables are titled: Station and Area Type Code; Effects Stations Identification List; Cumulative Frequency Distributions; Metal Corrosion; Dyed Fabrics; Silver Tarnishing; Lead Plates; Dustfall; Nylon Deterioration; Rubber Cracking; Sticky Paper (Wind Blown particulates); and Station Index (Alphabetized by State).

6. Systems Analysis of the Effects of Air Pollution on Materials.
R. L. Salmon. NTIS Report PB-209192, January 15, 1970, 196 pp.
(Fe70-13)
7. The Weathering and Performance of Building Materials. J. W. Simpson and P. J. Horrobin, eds. Medical and Technical Publishing Co. Ltd., 1970, 277 pp. (Fe70-17)
8. Use of Environmental Data in Atmospheric Corrosion Studies.
J. F. Stanners. Brit. Corros. J., v. 5, No. 3, 1970, pp. 117-121.
(Fe70-18)

1969

1. Calculation of Moistening and Metallic Corrosion in Atmospheric Environment. A. I. Golubev and M. K. Kadyrov. Proc. 34d Intern. Congr. on Metallic Corrosion, Moscow (1966), Swets-Zeitlinger, Amsterdam, Holland, v. 4, 1969, pp. 522-531. (Fe69-24)
2. Corrosion in the Atmosphere. P. Atterby. NTIS Report N71-26259, November 1969, 9 pp. (Swedish). (Fe69-25)
3. Corrosion of Metals in the Tropics. B. Sanyal, G. K. Singhania and J. N. Nanda. Proc. 3rd Intern. Congr. on Metallic Corrosion, Moscow (1966), Swets-Zeitlinger, Amsterdam, Holland, v. 4, 1969, pp. 542-543. (Fe69-26)
4. Studies on Corrosion of Metals Provoked by Gaseous Pollutants. B. Sanyal, G. K. Singhania and D. V. Bhadwar. Proc. 3rd Intern. Congr. on Metallic Corrosion, Moscow (1966), Swets-Zeitlinger, Amsterdam, Holland, v. 4, 1969, pp. 454-464. (Fe69-36)

1968

1. Atmospheric Exposure of Light Metals. S. Brandt and L. H. Adam. Metal Corrosion in the Atmosphere, ASTM STP 435, American Society for Testing and Materials, 1968, pp. 95-128. (A168-2)

2. Composition and Structure of Natural Patinas. III. Tin, Lead, and Their Alloys. 1873 to 1964. S. Z. Lewin and S. M. Alexander. Art Archaeol. Tech. Abst., v. 7, No. 2, 1968, pp. 173-190.*

A collection of abstracts of work from 1873 to 1964 is reported. The corrosion chemistry of Sn appears to be relatively simple, for the only Sn compounds that have been identified on the metal or its alloys, even after prolonged exposure under the widest diversity of conditions, are SnO, SnO₂ and SnS. The tin compounds are under all ordinary conditions among the most insoluble substances in the realm of metal oxides, and this accounts for their great stability and persistence. They form an adherent and coherent coating on the surface that protects the underlying metal from progressive attack and resists the action of other reagents. Pb, on the other hand, appears to be capable of yielding as rich a variety of corrosion products as Zn. Corrosion products that have been identified on Pb include the carbonate, bicarbonate, sulfate, sulfide, chloride, hydroxide, mono and dioxide, nitrate, and superoxide. Further studies of the corrosion chemistry of Pb (using x-ray diffraction instead of simple chemical analysis, for example) as well as the composition of naturally occurring patinas on Pb artifacts, are necessary before such information can begin to provide any useful archaeological historical information.

3. Corrosion of Metals by Aqueous Solutions of the Atmospheric Pollutant Sulfurous Acid. W. McLeod and R. R. Rogers. Electrochemical Technology, v. 6, No. 7-8, July-August 1968, pp. 231-235. (Fe68-3)
4. High Pressure Electrical Contacts. J. King. Proc. 1968 Electrical Components Conference, May 8-10, 1968, pp. 454-458. (Fe68-9)
5. Investigations of the Corrosion-Causing Properties of Volatile Acids and Anhydrous Acids. E. Iaengle. Eidgenoessische Technischen Hochschule, Zurich, Switzerland. Ph.D. Thesis, 1968, 43 pp. (German). (Fe68-11)
6. Patina On Old Metal Objects. J. Lehmann. Monographs of the National Museum in Pozan. v. 2, 1968, pp. 1-125 (Polish). (Fe68-15)
7. Resistance of Titanium-Base Alloys to Atmospheric Corrosion. M. L. Grenlee and L. F. Plock. Metal Corrosion in the Atmosphere, ASTM STP 435, American Society for Testing and Materials, 1968, pp. 33-38.

Eight titanium alloys were included in the 1957 ASTM Committee G-1 (formerly B-3) program to determine the atmospheric corrosion behavior of nonferrous metals and alloys. Representative alloys of the alpha, alpha-beta, and beta type were evaluated. Based upon results of weight change measurements and tension tests, two- and seven-year exposures at four prominent ASTM test sites resulted in no significant corrosion. Slight staining was observed, but there was no appreciable weight change.

8. Tarnishing and Contamination of Metals. W. E. Campbell and U. B. Thomas. Proc. Engineering Seminar on Electrical Contact Phenomena, Illinois Inst. Technology, Chicago, Ill., November 11-15, 1968, pp. 233-265. (Cu68-10)

1967

1. Bridging with Steel. J. A. Cran and I. M. Park. Engineering J., February 1967, pp. 18-25. (Fe67-3)
2. Corrosion Products Forming on Cadmium in Natural and Artificial Corrosion Environments. T. Biestek and J. Niemiec. Pr. Inst. Mech. Precyz., v. 15, No. 1, 1967, pp. 42-46.**

Corrosion products on steel specimens coated with electrodeposited cadmium in the bath containing Cd 26, NaOH 55, NaCN 90, and NiSO_4 1.5 g/l, at room temperature and current density of 1.5 amp/dm² were studied. The investigations were conducted in an industrial atmosphere containing on the average 1.0 mg SO₂ and 1200 dust particles/cc. of air and in the coastal and rural atmosphere. Moreover, the tests were carried out in a 60-liter chamber, into which 2-liter SO₂ and CO₂ were introduced every day. The chamber temperature was $37 \pm 0.5^\circ$ and the relative humidity >95 percent. The specimens were exposed to the natural environments for 9 years. The specimens tested in the artificial environment were kept in the chamber for 5 hours and then were dried for 10 hours in the room environment. The corrosion products were examined by X-ray diffraction using Cu K α radiation. The components of the products varied with corrosion medium: in the industrial environment, these were $\text{CdSO}_4 \cdot \text{H}_2\text{O}$, CdS, and $\text{CdCl}_2 \cdot \text{H}_2\text{O}$; in coastal, CdCO_3 , $2\text{CdCO}_3 \cdot 3\text{Cd}(\text{OH})_2$, and CdCl_2 ; in rural, CdCO_3 ; and in the artificial environment, $\text{Cd}(\text{OH})_2$, CdCO_3 , CdS, and $\text{CdSO}_4 \cdot \text{H}_2\text{O}$.

1966

1. Atmospheric Corrosion of Metals. N. D. Tomashov. Chapt. 14 in Theory of Corrosion and Protection of Metals, MacMillan, 1966, pp. 367-396. (Fe66-2)
2. Atmospheric Corrosion of Steel, Zinc, Cadmium, Copper, and Aluminum in Different Coastal and Continental Regions. G. K. Berukshtis and G. B. Klark. Corrosion of Metals and Alloys, Collection No. 2, Israel Program for Scientific Translations, Jerusalem, 1966, pp. 281-297. (Fe66-4)
3. Atmospheric Corrosion of Zinc- and Cadmium-Coated Steel and the Coefficients for Recalculating the Results of Accelerated Corrosion Tests Into Data for Service Conditions. P. V. Strekalov and G. K.

Berukshtis. Corrosion of Metals and Alloys, Collection No. 2, Israel Program for Scientific Translations, Jerusalem, 1966, pp. 221-233. (Zn66-3)

4. Corrosion Behavior of Some Metallic Materials In Liquid Sulfur Dioxide. L. Rivola, T. Bazzan, M. Piro and G. Bombara. Proc. 2nd Intern. Congr. Metal. Corrosion, New York (1963), National Association of Corrosion Engineers, Houston, TX, 1966, pp. 418-423. (Fe66-6)
5. Current Ideas in the Philosophy of Testing Electrical Contacts. H. B. Ullsh. IEEE International Convention Record, v. 14, No. 9, 1966, pp. 35-38. (Cu66-7)
6. Tarnish Films on Electric Contact Materials. R. V. Chiarenzelli. Proc. Third Intern. Research Symposium on Telectrical Contact Phenomena, June 6-10, 1966, pp. 85-93. (Cu66-8)
7. The Action of Environment on Museum Objects. Part I. Humidity, Temperature, Atmosphere Pollution. N. Stolow. Curator, v. 9, 1966, pp. 175-185.

The author surveys the effects of uncontrolled humidity, temperature and pollution levels on various materials in museums, and discusses a "safe" atmosphere for art objects. Psychrometers, which may be handily used to measure relative humidity throughout a museum, are available at various prices and should be used to help establish humidity control.

8. The Effects of Air Pollution on Electrical Contact Materials. R. V. Chiarenzelli and F. L. Joba. J. Air Pollution Control Assoc., v. 18, No. 3, 1966, pp. 123-127. (Cu66-9)

1965

1. Atmospheric Corrosion. G. T. Bakhvalov and A. V. Turkovskaya. Chapt. in Corrosion and Protection of Metals, translated and edited by G. Isserlis, Pergamon, New York, N.Y., 1965, p. 55.

A description of the atmospheric corrosion of metals is given.

2. Atmospheric Corrosion of Steels Related to Meteorological Factors in Japan III. Results of Weathering Tests Conducted on Metallic Coatings for 3 Years. K. Oma, T. Sugano, T. Ueki and Y. Hirai. Boshoku Gijutsu, v. 14, No. 3, 1965, pp. 103-108 (Japanese). (Al65-1)

3. Significance of Corrosion Testing Process with Special Consideration of the SO₂ Test According to DIN 50018. W. Kesternich. Werkst. Korrosion, v. 16, 1965, pp. 193-201 (German). (Fe65-15)
4. The Significance of Sulfur Dioxide in the Atmospheric Corrosion of Metals. G. Schikorr. Korrosion, No. 17, 1965, pp. 27-34. (Fe65-20)

1964

1. An Electrical Resistance Method for Measuring Rates of Corrosion of Electrodeposited Metals in Laboratory Tests. F. Enrico, V. Riccio and B. Martini. Product Finishing, v. 17, No. 5, May 1964, pp. 74-79. (Cu64-1)
2. Atmospheric Effects on Friction and Wear. W. E. Campbell. Machine Design, August 27, 1964, pp. 186-192. (Cu64-3)
3. Electrochemical Characteristics of Atmospheric Corrosion. H. Kaesche. Werkst. Korros., v. 15, No. 5, 1964, pp. 379-390.

Formation of corrosive electrolytes under the influence of water adsorption and other atmospheric impurities on metallic surfaces are discussed. Kinetics of electrolytic corrosion is assessed on the basis of corrosion with evolution of hydrogen, corrosion with reduction of dissolved oxygen, and corrosion with reduction of dissolved sulfur dioxide. In connection with nonuniform corrosion, conditions for the appearance of various types of differential aeration cells are discussed on the basis of nonuniform corrosion with emphasis on oxide-coated metals.

4. New Method of Determining the Aggressiveness of Different Atmospheres Toward Metals. A. Hache. Rev. de Metallurgie, v. 61, No. 4, April 1964, pp. 395-397 (French).

Chlorides settling on specially shaped specimen are caught in a glass flask. The purpose is to determine whether a simple relation exists between the severity of corrosion by marine atmospheres and the quantity of salt collected on a specimen. If so, the method will be helpful in avoiding especially aggressive microclimates.

5. The Effect of Climate on Atmospheric Corrosion of Metals. J. C. Hudson. Werkst. Korros., v. 15, No. 5, 1964, pp. 363-370.

The effect of climate on atmospheric corrosion of metals is discussed and the importance of relative humidity stressed. Other factors are gaseous and solid contaminants in the atmosphere, temperature, mass and shape of the metal, orientation of the metal with respect to soil and sky, and air velocity.

6. The Influence of Corrosion Products on the Long-Term Progress of Atmospheric Corrosion. K. Barton and D. Knotkova-Cermakova. *Werkst. Korros.*, v. 15, No. 5, 1964, pp. 374-378.

The long-term progress of atmospheric corrosion of metals is a function of the mechanism of formation of the corrosion products and their properties. The bonding type of the corrosion stimulator (for example, SO_2) in the corrosion products and their capacity to absorb H_2O are significant. Long-term corrosion is brought about in 4 steps: formation of an electrolytic layer, destruction of the primary oxide layer, formation of solid corrosion products, and corrosion in the presence of a layer of solid corrosion products. In assessing long-term corrosion, corrosion protection of metals by alloying and by coatings is discussed.

7. The Influence of Sulphur Dioxide on the Atmospheric Corrosion of Metals. G. Schikorr. *Werkst. Korros.*, v. 15, No. 5, 1964, pp. 457-463. (Fe64-4)

1963

1. Atmospheric Corrosion. R. K. Swandby. *Corrosion Resistance of Metals and Alloys*, edited by F. L. Laque and H. R. Copson, Reinhold Publishing, New York, 2nd ed., 1963, pp. 45-47. (Fe63-1)
2. Rapid Method For Determining Corrosivity of Atmosphere at Any Location. D. P. Doyle and H. P. Godard. *Nature*, v. 200, No. 4912, 1963, pp. 1167-1168

In using the wire-on-bolt test to measure galvanic corrosion of metals it is indicated how to provide numerical assessment of corrosivity of the atmosphere in periods as short as 3 months, as compared with several years required in conventional atmospheric exposure tests.

1962

1. Atmospheric Corrosion by Electrolyte Nuclei. B. Sanyal and D. V. Bhadwar. *J. Sci. Industr. Res.*, v. 21D, 1962, p. 243. (Fe62-2)
2. Atmospheric Corrosion of Metals. Some Questions of Theory. I. L. Rosenfeld. *Proc. 1st Intern. Congr. on Metallic Corrosion*, London (1961), Butterworth, London, 1962, pp. 243-248. (Fe62-3)
3. Comparative Outdoor Exposure Tests of Electrodeposited Zinc and Cadmium Coatings on Steel in a Natural Industrial Atmosphere. T. Biestek. *Proc. 1st Intern. Congr. Metallic Corrosion*, London (1961), Butterworth, London, 1962, pp. 269-274. (Zn62-4)

4. Effects of Air Pollution on the Atmospheric Corrosion Behavior of Some Metals and Alloys. E. A. Tice. J. Air Pollution Control Assoc., v. 12, 1962, pp. 553-559. (Fe62-6)
5. Electrical Contact Materials: Properties and Selection. E. Freudiger. Electro-Technology, v. 69, 1962, pp. 72-78. (Cu62-4)
6. Improving Contact Reliability in Low-Level Circuits. J. J. McManus. Electro-Technology, v. 69, 1962, pp. 98-101. (Cu62-5)

1961

1. Atmospheric Corrosion. U. R. Evans. Chapt. 8 in The Corrosion and Oxidation of Metals, Edward Arnold Ltd., 1961, pp. 481-535. (Fe61-2)
2. Corrosion In Buildings. P. J. Sereda. Canadian Building Digest, Report No. CBD-20, August 1961, 4 pp. (Fe61-5)
3. Effects of Atmospheric Contamination on Switching Noise. J. Bloomberg and W. E. Campbell. Proc. Engineering Seminar on Electrical Contacts, Pennsylvania State University, University Park, PA, June 11-15, 1961, pp. 95-107. (Cu61-3)
4. Effect of Nitrogen Tetroxide on Metals and Plastics. C. W. Alley, A. W. Hayford and H. F. Scott, Jr. Corrosion, v. 17, No. 10, October 1961, pp. 479t-484t. (Fe61-6)
5. The Resistance of Aluminum Alloys to Corrosion. E. H. Dix, Jr., R. H. Brown and W. W. Binger. Metals Handbook, v. 1, 8th edition, American Society for Metals, 1961, pp. 916-935. (Al61-3)

1960

1. Chemical Resistance to Ammonia of Construction Materials. A. E. Missan. Trudy Gosudarst. Inst. Priklad. Khim., v. 44, 1960, pp. 112-127 (Russian). (Fe60-3)
2. Evaporated Metal Films As Indicators of Atmospheric Pollution. J. P. Lodge, Jr. and B. R. Havlik. Int. J. Air Pollution, v. 3, No. 4, 1960, pp. 249-252. (Fe60-4)

3. Investigation of Surface Contamination of Fine Silver Contacts.
E. Freudiger. Proc. Engineering Seminar on Electrical Contacts,
Pennsylvania State University, University Park, PA, June 5-10, 1960,
pp. 45-51.

Surface contamination influences in a complex manner the performance of electrical contacts. Despite the fundamental work by Holm, Bell Laboratories, Chaikin, and many others, it is often difficult to correlate increased contact resistance or variation in welding or erosion characteristics with the presence of certain contaminants. Malfunction of the contacts can occur although no foreign substance can be detected (which does not mean that it is not present), and sometimes when the presence of contamination is well established the contacts continue to work satisfactorily.

This points out the necessity of (a) determining the source of the contaminating matter and the manner of deposition or formation of the foreign material on the contact surface, and (b) measuring the influence of the contaminants on contact resistance, welding tendency, or contact erosion.

4. Measurement of Surface Moisture and Sulfur Dioxide Activity at Corrosion Sites. P. J. Sereda. ASTM Bull. No. 246, 1960, pp. 47-48.*

A dew detector amplifier is used to detect surface moisture on corrosion specimens. The amplifier actuates a temperature recorder. Temperature, time-of-wetness, and sulfur dioxide concentration correlate with corrosion rates. Sulfur dioxide is determined by the lead peroxide method.

1959

1. Deterioration of Materials in Polluted Atmospheres. J. E. Yocum.
Corrosion, v. 15, No 10, October 1959, pp. 541t-545t. (Fe59-5)
2. Electrochemical Study of Atmospheric Corrosion of Metals. N. D. Tomashov and A. A. Lokotilov. Korroziya i Zashchita Stalei, 1959, pp. 158-170 (Russian).*

The procedure for electrochemical investigation of atmospheric corrosion is presented and results are discussed. The appraisal is described. The method proved that all processes of corrosion in the atmosphere are electrochemical in nature. By applying this method it is possible to appraise the corrosive atmospheric conditions and to define the effects of different factors (water, sulfur dioxide, and volatile retarders of corrosion) on the rate of atmospheric corrosion.

3. Measurement of Surface Moisture. P. J. Sereda. ASTM Bulletin, No. 238, 1959, pp. 61-63. (Zn59-3)

4. Mechanism by Which Nonferrous Metals Corrode in the Atmosphere.
P. M. Aziz and H. P. Godard. Corrosion, v. 15, No. 10, 1959,
pp. 529t-533t. (A159-3)

1958

1. Measures for the Prevention of Corrosion by Preparation of the Atmosphere.
A. Kutzelnigg. Korrosion X, Ber. Korrosionstag. Koln (1957), 1958,
pp. 7-13 (German).

Atmospheric corrosion is attributed to oxygen, water, electrolytes, dust, formation of elements, and formation of protective coatings. Experimental data are presented for the various impurities as determined at various locations. It is recommended that the relative humidity be kept below certain limits and that the condensation of moisture be prevented. Purification of the atmosphere is suggested by absorption, catalytic oxidation, and filtration. The passivation of metals by contact with inhibitor-coated papers is recommended.

1957

1. The Effects of Air Pollution on Buildings and Metalwork. R. J. Schaffer.
Air Pollution, edited by M. W. Thring, Butterworth Scientific, London,
1957, pp. 58-71. (Fe57-5)

1956

1. Atmospheric Exposure (Tests) of Electroplated Lead Coatings on Steel.
A. H. Durose. Symposium on Electroplated Metallic Coatings, ASTM
STP 197, American Society for Testing and Materials, 1956, pp. 97-104.
(discussion pp. 105-106).

Outdoor corrosion tests to determine the protection given by Pb coatings deposited from fluoborate and sulphamate solutions are summarized.

2. Atmospheric Galvanic Corrosion of Magnesium Coupled to Other Metals.
H. O. Teeple. Atmospheric Corrosion of Non-Ferrous Metals, ASTM STP
175, American Society for Testing and Materials, 1956, pp. 89-111.

Magnesium is studied in the forms of two alloys: AZ31X and M1. These magnesium alloys were coupled respectively with a number of metals and alloys. The data presented in this paper are the results of the evaluation of the first of three sets of specimens exposed at four different locations. Those represent either/or a combination of marine, industrial or rural atmospheres.

3. Galvanic-couple Corrosion Studies by Means of the Threaded Bolt and Wire Test. K. G. Compton and A. Mendizza. Atmospheric Corrosion of Non-ferrous Metals, ASTM STP 175, American Society for Testing and Materials, 1956, pp. 116-125. (Fe56-7)
4. Report of Subcommittee on Atmospheric Corrosion. H. R. Copson. Atmospheric Corrosion of Non-Ferrous Metals, ASTM STP 175, American Society for Testing and Materials, 1956, pp. 3-19. (Al56-4)
5. The Use of Lead and Tin Outdoors. G. O. Hiers and E. J. Minarcik. Atmospheric Corrosion of Non-Ferrous Metals, ASTM STP 175, American Society for Testing and Materials, 1956, pp. 135-140.

This paper is a partial summary of the 20-year atmospheric tests conducted by Subcommittee VI (Atmospheric Corrosion) of ASTM Committee B-3 on Corrosion of Non-Ferrous Metals and Alloys. The metals with which this section is concerned are: chemical lead, 1-percent antimonial lead and commercial tin. The data show that chemical lead and antimonial lead are remarkably durable in all of the test site exposures.

1955

1. Atmospheric Galvanic Couple Corrosion. K. G. Compton, A. Mendizza, and W. W. Bradley. Corrosion, v. 11, No. 9, 1955, pp. 35-44. (Fe55-1)
2. Corrosion Aspects of Air Pollution. L. Greenburg and M. B. Jacobs. Amer. Paint J., v. 39, No. 43, 1955, pp. 64-78. (Fe55-2)
3. Metal Coatings on Steel in Contact With Aluminum Alloys. Some Comparative Corrosion Tests. S. C. Britton and R. W. de Vere Stacpoole. Metallurgia, v. 52, 1955, pp. 64-70. (Fe55-4)
4. The Destructive Effects of Air Pollution on Materials. A. Parker. 6th Des Voeux Mem. Lecture, Proc. 22nd Annual Conf., Nat. Smoke Abatement Soc., Bournemouth, England, September 28, 1955, pp. 120-132. (Fe55-6)

1954

1. Deterioration of Materials - Causes and Preventive Techniques. G. A. Greathouse and C. J. Wessel. Reinhold Publishing, New York, N.Y., 1954, 835 pp.

Part I discusses the factors causing deterioration: climate, chemical and physical agents, biological agents. Part II is about "Materials and Their Preservation": metals, wood and wood products,

paper, textiles and cordage, leather, plastics and rubber, paints, varnishes, enamels and lacquers. Part III is about "Some Assembled Units and Their Preservation": electrical and electronic equipment, optical instruments and photographic equipment. Part IV presents "Some Special Aspect of Preservation": dehumidification, packaging, toxicological evaluation of preservatives.

1953

1. The Behavior of Metallic Contacts at Low Voltages in Adverse Environments. A. Fairweather. Proc. I.E.E.E., v. 100, pt. 1, 1953, pp. 174-182. (Cu53-2)

1952

1. Corrosion of Different Metals in Liquefied Sulfur Dioxide. J. Bollinger. Schweiz. Arch. angew. Wiss. u. Tech., v. 18, 1952, pp. 321-342 (German) (Fe52-2).
2. Corrosion of Metals. U. R. Evans. Soc. Chem. Industry (Chem & Industry), No. 41, October 11, 1952, pp. 986-993. (Fe52-3)

1951

1. Corrosion of Copper, Aluminum, and Magnesium and Their Alloys. M. Orman and E. Zalesinski. Hutnik, v. 18, 1951, pp. 96-101 (Polish). (Al51-1)

1950

1. Atmospheric Corrosion of Metallic Materials in Closed Spaces. G. Schikorr. Feinmech. u. Prazis, v. 54, 1950, pp. 3-8. (Al50-1)

1948

1. The Atmospheric Corrosion of Metals. G. Schikorr. Arch. Metallkunde, v. 2, 1948, pp. 223-230 (German). (Fe48-7)

1936

1. Corrosion Resistance of Metals and Alloys. R. J. McKay and R. Worthington. Amer. Chem. Soc. Monograph No. 71, Reinhold Publishing, New York, N. Y., 1936, 492 pp. (Fe36-2)

1929

1. Atmospheric Corrosion of Metals--3rd Report to the Atmospheric Corrosion Research Committee. J. C. Hudson. Trans. Faraday Soc., v. 25, 1929, pp. 177-252. (Al29-1)
2. The Relative Corrodibilities of Ferrous and Non-Ferrous Metals and Alloys. Part II--The Results of Seven Years' Exposure to Air at Birmingham. J. N. Friend. J. Inst. Metals, v. 42, 1929, pp. 149-155. (Fe29-2)

1927

1. Second Experimental Report to the Atmospheric Corrosion Research Committee. (British Non-Ferrous Metals Research Association). W. H. J. Vernon. Trans. Faraday Soc., v. 23, 1927, pp. 113-179.

This report is concerned with the behavior of typical metals and alloys on exposure to the atmosphere. It is divided into two parts, dealing respectively with "indoor" and "open-air" exposure tests, the former including associated laboratory experiments. It has shown that conclusions which hold good for a given set of conditions do not necessarily apply when those conditions are changed. This is exemplified by the influence of "impurities" in copper. Indoors, under conditions such that only tarnishing has to be considered, a given element exercises an effect which is either negligible, or in simple proportion to the amount of element present. Exposed to the open air however, the same element may exert an effect out of all proportion to its concentration. It would appear that protection against indoor tarnishing should be sought by methods other than modification of composition alone. Promising results have been obtained in connection with the formation of protective surface films.

MASONRY, STONE, AND CERAMICS

1982

1. Acid Rain: Impacts on the Natural and Human Environment. H. C. Martin. Materials Performance, v. 21, January 1982, pp. 36-39. (Fe82-3)
2. Analytical Methods Related to Building and Monument Preservation. I. Adler, S.E. Sommer, R. Gershon, and J.I. Trombka. chapt. in Conservation of Historic Stone Buildings and Monuments, National Academy of Sciences, Washington, D.C., 1982, pp. 163-182.

The most visible products of the weathering of stone materials are a consequence of the physical breakdown, i.e. the fragmentation and disintegration of mineral components. Somewhat less obvious are the dissolution of these minerals and subsequent formation of new compounds, frequently in the interstices as a result of the action of chemical and biological agents.

An early phenomenon that lends itself to study is the disruption of chemical bonds during physical and chemical disintegration and the formation of highly reactive surfaces. These reactions may include oxidation-reduction, disordering of the mineral structure and ion exchange processes with the eventual formation of microlayers of poorly crystalline materials and microsystems of cracks and fractures with precipitated coatings, cements and possible phase transformations as complicating factors.

The examination of these veneers present problems that are well matched by the techniques utilized in bulk characterization such as atomic absorption, X-ray fluorescence and optical emission spectroscopy. With regard to surfaces and near surfaces (defined as 10 Å to a few micrometers in depth) one may consider a variety of techniques some of which can be utilized in-situ offering the advantage of rapid and non-destructive analysis. The use of neutron, gamma and reflection spectrophotometry will be described as an example. Some of the other techniques which are applied in the laboratory, which also require minimal sampling, are electron spectroscopy, electron microprobe analysis, electron microscopy, and X-ray diffraction analysis. This paper examines the use of a number of these techniques pointing out where a given method or combination of methods is most applicable and the way in which the results may be related to the weathering processes that are occurring.

3. Atmospheric Corrosion of the Concrete Reinforcements and of Limestones and Marbles. T. Skoulikidis. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., pp. 807-826.

By weight loss measurements of the reinforcements of concrete from demolished buildings and dismantled ancient monuments, the Wagner's parabolic law for the corrosion progress is valid till 75 years. Using our kinetic data for the sulfation of CaCO_3 powder and marble thin

sections, a linear rate law is valid for progress of the reaction for gypsum films up to 300 Å in thickness. A parabolic law applies for greater thickness. The solid state diffusion of Ca^{2+} was located as the rate-determining step.

4. Atmospheric Corrosion Testing In the Federal Republic of Germany. G. Oelsner. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 797-806. (Fe82-18)
5. Characterization of Bricks and Their Resistance to Deterioration Mechanisms. G. C. Robinson. Chapter in Conservation of Historic Stone Buildings and Monuments, National Academy of Sciences, Washington, D.C., 1982, pp. 145-162.

Brick and mortar are building materials of excellent durability. Nevertheless, they are subject to deterioration processes that can reduce their effectiveness. The rate of deterioration is a function of composition, pore structure, manufacturing procedure, structural design and cleaning procedure. An appreciation of this relationship can assist in selecting restoration procedures for predicting future life of masonry walls.

Deterioration of masonry results from several mechanisms including freezing and thawing, salt crystallization, chemical attack by water and other substances, moisture expansion, other internal expansive reactions, and mismatch in dimensional characteristics of wall components.

The susceptibility of brick to each mechanism is determined by pore structure and composition. The glassy and amorphous phases are key items of composition. Illustrations are presented of the significance of glass phase composition.

The manufacturing procedure, structural design and cleaning procedure can exert additional influence on deterioration mechanisms and rates. The danger of waterproof coatings is presented.

6. Environment, Microenvironment, and the Durability of Building Materials. P. J. Sereda and H. E. Ashton. J. Durability of Building Materials, v.1, No. 1, 1982, pp. 49-66. (Fe82-37)
7. Measurement of Local Climatological and Air Pollution Factors Affecting Stone Decay. I. Tombach. Chapter in Conservation of Historic Stone Buildings and Monuments, National Academy of Sciences, Washington, D.C., 1982, pp. 197-210.

The atmosphere is one of the prime contributors to the decay of stone in historical buildings. The atmospheric factors causing such decay range from the natural consequences of rainfall, wind, frost, and heat to the more complicated chemical and biological processes resulting from pollution of the atmosphere. A list of such factors, can be broken down into groups depending on:

- (1) The available moisture (rain, fog, humidity),
- (2) The temperature of the air,
- (3) The cooling and heating of surfaces (by wind and radiation) and the evaporation and condensation of moisture on them,
- (4) The motion of the air (wind),
- (5) The presence of air constituents and contaminants (gaseous and aerosol).

The behavior of these factors depends on the time of day and season of the year, as well as on large-scale meteorological phenomena and human activities.

Techniques for measuring parameters within each group have been well-developed in the fields of meteorology, aerodynamics, and air pollution. These methods can be applied to assist in research on stone preservation and can also provide data for developing strategies to protect specific structures.

8. Photographing Architectural Decay. S. Z. Lewin and M. E. Dunn. Technical Photography, August 1982, pp. 18-20.

Photographing the condition of building facade on sculptured surface is an essential tool in preserving and restoring historic structures. Acid rain, freeze-thaw cycling, salt crystallization, microbiological activity, and water-leaching are among the factors that damage stone and masonry. It is possible through long distance macrophotograph to quickly, easily, and inexpensively undertake investigations and solve problems of stone and masonry damage that would otherwise not be practicable.

9. The Arch of Peace in Milan. 1. Researches on Stone Deterioration. G. Alessandrini, G. Sala, G. Biscontin, and L. Lazzarini. Studies in Conservation. v. 27, 1982, pp. 8-18.

Chemical, mineralogical, petrographical, physical and structural analyses were performed on marble samples from the Arch to study chemical weathering, variations in physical properties, role of microorganisms, and thermohygrometric parameters, including air pollution at the monument.

The environmental data show that the monument is particularly exposed to winds, remarkable thermal fluctuations, and frequent frost periods (mostly 1855-1955). Unlike the historic center of Milan, the SO₂ levels at the Arch are low thanks to the lack of surrounding buildings and to the continuous ventilation. In fact, sulfates were rarely found in the degraded surface. In addition, the marked schistosity and remarkable impurity of the marbles favor preferential attacks with different alterations along the same schistosity planes. The deterioration of the marbles is related mainly to the seasonal thermal fluctuations.

10. The Mechanism of Masonry Decay through Crystallization. S. Z. Lewin. Chapter in Conservation of Historic Stone Buildings and Monuments, National Academy of Science, Washington, D.C., 1982, pp. 120-144.

One of the most ubiquitous and extensive sources of the deterioration of stone, brick, mortar, plaster and concrete is the channels and cracks at and near exposed surfaces. Liquid water containing dissolved matter deposits its burden of solute wherever evaporation can occur. The site of this crystallization is determined by the dynamic balance between the rate of escape of water from the surface and the rate of resupply of solution to that site. The former is a function of temperature, air humidity, and local air currents. The latter is controlled by surface tension, pore radii, viscosity, and the path length from the source of the solution to the site of the evaporation.

The detailed nature of this balance determines the form that the decay will take. If the rate of resupply of solution to the surface is sufficient to keep pace with the rate of evaporation, the solute deposits on the external surface and is characterized as an efflorescence. If the rate of migration of solution through the pores of the masonry does not bring fresh liquid to the surface as rapidly as the vapor departs, a dry zone develops just beneath the surface. Solute is then deposited within the stone, at the boundary between the wet and dry regions. The consequence of this type of crystallization is the generation of a spall, flake, or blister.

The site of crystal deposition can be predicted by application of the physical chemical laws governing capillarity, viscous flow, and diffusion. These considerations disclose the quantitative relationship between the porosity of the masonry and the dimensions of the flakes, blisters, or spalls that develop, as well as the manner in which the decay progresses.

Data stemming from controlled experiments in which salt decay is induced in laboratory specimens, together with measurements on examples of salt decay found in buildings and monuments in a variety of environments, confirm the validity of these insights.

11. Wet and Dry Surface Deposition of Air Pollutants and Their Modeling.

B. B. Hicks. Chapter in Conservation of Historic Stone Buildings and Monuments, National Academy of Sciences, Washington, D.C., 1982, pp. 183-196.

The net rate of delivery of trace gases to receptor surfaces is largely determined by the chemical affinity of surface materials for the gas in question; if molecules of the gas are captured efficiently or react quickly upon contact with the surface, then high surface flux densities can be expected. Large particles are deposited by gravitational settling and by inertial impaction; the efficiency of their capture depends on their shape and the structure of the surface at the point of impact. Small, sub-micron particles have difficulty penetrating the quasi-laminar air layer adjacent to smooth surfaces, but once they contact the surface they are efficiently retained by van der Waals forces. All particles are susceptible to electrostatic forces that will encourage deposition if either the particles or the receptor surfaces carry an electrical charge. The presence of temperature and humidity gradients near the surface can also promote or hinder the deposition of particles. Most of these matters have been investigated in studies of deposition to relatively uniform surfaces of pipes or plates in wind tunnels. Extrapolation to the real world case of complicated surface shapes is sufficiently uncertain that quantitative statements cannot be made. The role of rainfall and other

kinds of atmospheric precipitation is equally complicated. Current ecological concern about the acidity of rain has focused attention on adverse effects associated with precipitated chemistry, but it must be recognized that rainfall provides a natural cleansing mechanism in many instances. In highly polluted areas, it is possible that the major effect of rainfall will be to remove some previously deposited pollutants from exposed surfaces and promote the subsequent deposition of soluble gases and small particles to those areas (such as crevices) which remain moist.

1981

1. Acid Rain and Material Damage in Stone. N. S. Baer and S. M. Berman. Final Report to EPA-NADP Acid Precipitation Program, North Carolina State University, Raleigh, North Carolina, June 1, 1981, 55 pp.

The use of marble headstones in National Cemeteries as a statistical universe for materials damage effects on stone is reviewed. A plan of work including sampling methods, physical measurements, record verification, and statistical analysis is described. Results are presented for ten National Cemeteries: four in New York State (Bath, Cypress Hills, Long Island, Woodlawn), and five in other areas (Arlington, Virginia; Fort Logan, Colorado; Golden Gate and San Francisco, California; Santa Fe, New Mexico; Soldier's Home, Washington, D.C.). Illustrations of hypothesis testing and regression analysis are given.

2. Acid Rain: Impacts on the Natural and Human Environment. H. C. Martin. Paper No. 114, Corrosion/81 (Toronto, Canada), National Association of Corrosion Engineers, Houston, TX., April 6-10, 1981, 7 pp. (Fe81-1)
3. Airborne Carbon Particles and Marble Deterioration. M. del Monte, C. Sabbioni, and O. Vittori. Atmospheric Environment, v. 15, No. 5, 1981, pp. 645-652.

Oil-fired carbonaceous particles are consistently found inside gypsum calcite layers covering some marbles located in northern Italy urban areas. A series of analyses performed on the particles and on thin sections of sulfated layers show that these particles are probably the most important, if not the determinant, agents of the observed deterioration. Some observations seem also to indicate the way they act. The present results, combined with the origin of these particles, as indicated by their nature, support the hypothesis that the reported marble deteriorations affecting our artistic heritage actually started after the last war.

4. An Air Pollution Survey Inside the Basilica of Torcello in Relation to the Deterioration of Mosaics. V. Fassina, A. Bonarrigo, and A. Ongaro. The Conservations of Stone.II. Contributions to the International Symp. (October 27-30, 1981), edited by R. Rossi-Manaresi, 1981, pp. 401-415.

The state of conservation of the mosaics of the Basilica of S. Maria Assunta of Torcello is not very good. A stethoscopic survey pointed out that a widespread detachment of the mosaic is more frequently present in the lower parts. This is probably due to the migration of soluble salts rising in the walls, which during the evaporation phase crystallize under the surface. A thermovision survey showed the presence of cold zones in the lower parts (probably due to rising damp) where greater detachment of the mosaics was observed. On these colder zones gaseous and particulate pollutants can be removed from the atmosphere by the condensation of water vapour and as they remain in contact with the surface during the whole condensation phase may react with the lime mortar binding the tesserae. Late winter periods are the most dangerous because the condensation processes are more frequent and are associated with the higher sulfur dioxide and sulfuric acid concentrations.

5. Dissolution of Carbonatic Grain Cement of Sandstones by Sulfuric Acid Attack. R. Snethlage. Conservation of Stone. II. Contributions to the International Symp. (October 27-30, 1981), edited by R. Rossi - Manaresi, 1981, p. 25.

The experiments were carried out with Baumberger Sandstein, Regensburger Grunsandstein and were compared with pure Dolomite using 0.1, 0.01 and 0.001 m sulfuric acid for dissolution. The experimental conditions were 1) excess of acid, 2) excess of powdered rock, 3) percolation of sulfuric acid through small disks of Regensburger Grunsandstein. The reaction between the carbonates and the sulfuric acid is very fast. The curves show a nearly parabolic slope. The end of the reaction is determined either by the complete dissolution of the carbonatic cement or by the consumption of the acid. Dolomite is dissolved congruently. In a wide range, the velocity constants of the reactions are equal for calcite and dolomite.

6. Poland - The Most Polluted Country in the World. L. Timberlake. New Scientist, v. 92, No. 1276, October 22, 1981, pp. 248-250. (Fe81-11)
7. Pollutant Effects on Stone Monuments. K. L. Gauri and G. C. Holden. Environmental Science and Technology, v. 15, No. 4, 1981, pp. 386-390.

An oil refinery is being built nearly 30 km upwind from the Taj Mahal in Agra, India. This refinery is expected to emit 25-30 tons of sulfur dioxide daily, which is likely to travel towards the Taj Mahal from October to March due to the prevailing northwesterly winds. Such SO₂ emissions are expected to corrode the marble at the Taj Mahal in the same fashion that air pollution has contributed to the corrosion of marble at the nearly 70 year-old Field Museum of Natural History in Chicago.

8. Quantitative Study of the effect of Air Pollution on the Corrosion of Stone. S. Luckat. Staub.-Reinhalt. Luft, v. 41, No. 11, 1981, pp. 440-442 (German).

The annual means of immission rate for Cl^- and SO_2 in various locations, in Germany, are less than 26.5 and 6.6-126.0 mg/m^2 day, respectively. The corrosion effect of air pollution by SO_2 is evidenced by the near correlation between the immission rate and the corresponding SO_2 contents on the exposed stone surface in the same measuring stations. The effect of Cl^- on stone corrosion is less pronounced.

9. The Air Pollution Contribution to Stone Deterioration: Investigating the Weathering of the Bowling Green Custom House, New York City. R. A. Livingston. *Technology and Conservation*, v. 6, No. 2 (Summer), 1981, pp. 36-39.

As part of an extensive program to evaluate the influence of atmospheric contaminants on stone deterioration, an air pollution monitoring project was undertaken at the Old Custom House. The building was instrumented to detect gaseous pollutants and solid particulates. Also included in the study was an evaluation of a specialized air pollution monitor from Germany.

10. The Weathering of the Limestone of Trani Cathedral. U. Zezza. *Conservation of Stone. II. Contributions to the International Symp.* (October 27-30, 1981), edited by R. Rossi-Manaresi, 1981, p. 315.

The limestone (Trani stone) of the internal surface of the masonry of the Cathedral of Trani, among the most important monuments of Romanesque in Apulia (Italy), is suffering a rapid process of weathering which takes place in connection with the principal constituents of the rock (grains and matrix) or of the organic structures (fossils) and the inorganic ones (stylolites, recemented cracks, laminations, dessiccation cracks and sheet cracks). The weathered stone, principally represented by calcarenites, comes into contact with condensation waters which show an enrichment in ions Ca^{2+} , Na^+ , Cl^- , HCO_3^- and, subordinately in ions Mg^{2+} and SO_4^{2-} . The saline content of the condensation waters is higher than the saline content of the rain waters that fall down outside. On the weathered limestone of the internal surface of the masonry calcite, trona, halite and gypsum precipitate. On the external surface of the masonry the rain water continually washes away the exposed surfaces.

11. Weathering Rates on Marble Tombstones at a Sydney Cemetery. D. Dragovich. *ICCM Bulletin*, v. 7, No. 1, 1981, pp. 27 - 31.

On most natural rock outcrops, and the majority of stone used for building or monumental purposes, the measurement of surface loss by weathering over specified time periods is frequently not possible, because the condition of the original surface of the stone is unknown. Marble tombstones have several advantages for the study of weathering rates: a temporal benchmark for the commencement of weathering in fresh rock is provided by the inscription date, and lead lettering - which persists in a virtually unaltered state - indicates the position of the original polished stone surface. (When tombstones are cut, the surface is polished, letters are carved into the polished surface, and customarily

the carved letters are filled with lead flush with the polished surface). The amount of surface loss by weathering over known time spans can thus be established by measuring the height to which lead lettering currently stands above the marble surface.

The adverse effects of sulphur dioxide on marble monuments in cities has been well documented, but the possible accelerating effects of salt weathering on surface loss of marble has not received attention. Within the Sydney metropolitan area, a cliff-top cemetery was chosen to investigate whether the action of salts in a nearshore environment hastened the weathering of marble and this interim report discusses the progress of this work. Field measurements have been completed, but aerosol data and chemical analysis of calcite grains and other loose rock fragments are not yet available.

Marble weathers principally by solution and, although rates of surface reduction over different decades were not uniform in the tombstones studied, there was a general absolute increase in weathering loss with increasing age. On tombstones exposed for less than 45 years, surface reduction was greater between larger lead lettering than between smaller letters; the protection afforded by small lead lettering was not evident on tombstones erected more than 80 years ago. The measurements made did not support the hypothesis that the presence of sea-spray drift accelerated weathering loss from marble, and irregular rates of surface reduction on individual tombstones resulted from impurities present in the stone.

12. Workers Use Space-Age Technology to Restore Acropolis. L. B. Fleming. Los Angeles Times, November 1, 1981, Part I-A, pp. 1-3.

Spurred by a Greek chemist's discoveries, engineers and scientists are applying space-age materials and technologies in a new effort to preserve what is left of the marvels of the Acropolis.

The discoveries are:

1. Washing stone antiquities does great harm, for it removes the gypsum that crusts the surface and preserves some of the shape of the original. An alternative technique for consolidating the gypsum and preserving the surface is proposed.
2. Coating antiquities with plastic and other protective surfaces, widely practiced on commercial buildings, accelerates the deterioration in an irreversible way.

1980

1. Ailing Treasures. J. Hansen. Science 80, September 1980, pp. 58-61.

European researchers have discovered that certain bacteria are devouring the Greek Parthenon, Egypt's Temple of Karnak and scores of other famous buildings and sculptures. These bacteria belong to several families: the most dangerous one is the *Thiobacillus thioparus* which converts through its metabolic system the gas sulfur dioxide in air into

sulfuric acid, the latter serving as their digestive fluid; other bacteria generate nitric acids or organic acids. Curri, the scientist who discovered these bacteria, and his colleagues have evolved a method of treatment which is to spray the marble with antibiotics. This helps, but the microbial illness afflicting the many ancient monuments and art work grows more grave day by day.

2. A Review of Air Pollutant Damage to Materials. J. E. Yocum and A. R. Stankunas. Draft Report to Environmental Criteria and Assessment Office, Office of Research and Development, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, December 1980, 92 pp. (Fe80-2)

3. Arivederci, Roma. Acid Rains on the Eternal City. Canadian Heritage, October 1980, p. 34.

The effect auto emissions are having on the historical treasures of Rome and the actions being taken to remedy these effects is discussed.

4. Background and Principles of Long-Term Performance of Building Materials. S. E. Pihlajavaara. Durability of Building Materials and Components, ASTM STP 691, edited by P. J. Sereja and G. G. Litvan, American Society for Testing and Materials, 1980, pp. 5-16. (Fe80-4)

5. Buildings and Acid Rain. M. E. Weaver. Canadian Heritage, Heritage Canada Foundation, Toronto, October 1980, pp. 53-55.

The major victims of acid rains and the associated pollution products are, tragically enough, the very building stones which have become the byword of permanence in innumerable societies since the ancient Egyptians first built "for eternity." There is no magic plastic coating or "snake oil" to prevent this destruction of our heritage stonework. The only remedy is to stop the pollution.

6. Concrete Overlays for the Protection of Reinforced Concrete Against Corrosion. D. G. Manning and B. Chojnacki. Durability of Building Materials and Components, ASTM STP 691, edited by P. J. Sereja and G. G. Litvan, American Society for Testing and Materials, 1980, pp. 193-205.

Portland cement and modified portland cement concrete overlays were placed on reinforced concrete base slabs containing differing quantities of added chlorides. The specimens were ponded intermittently with sodium chloride solution. Concrete overlays were effective in retarding the penetration of chloride ions. Resistance to chloride penetration was improved by decreasing the water/cement ratio of the concrete and by the use of a latex modifier or internally sealing with wax. Initially high concentrations of chloride ions within the base concrete were redistributed within the base and the overlay. The concrete overlays

caused a decrease in corrosion activity of reinforcing steel embedded in concrete containing more chloride than the chloride content corrosion threshold. Cracks accelerated the onset of corrosion of intercepted reinforcing bars.

7. Critical Review of the Available Physicochemical Material Damage Function of Air Pollution. M. Benarie. Report No. EUR-6643, Commission on the European Communities, 1980, 97 pp. (Fe80-8)
8. Design Determines Durability. G. K. Garden. Durability of Building Materials and Components, ASTM STP 691, edited by P. J. Sereda and G. G. Litvan, American Society for Testing and Materials, 1980 pp. 31-37.

Durability of a material cannot be considered rationally except in the context of that material in service and the environment in which it must function, since it is the interaction of elements of the environment with a material that determines its durability. By analysis of numerous examples it will be demonstrated that the relative position of materials comprising any building element, in conjunction with the boundary conditions, determines both the functions each material will perform and the environmental conditions to which each material will be subjected in service. Design, being the process of deciding upon what material to use and where, determines durability.

9. Determination of the Source of Surface Deterioration on Tombstones at the Jewish Cemetery in Prague. J. Sramek. Studies in Conservation. v. 25, 1980, pp. 47-52.

Mass spectrometry of the calcium sulfate alteration product on the surface of the calcareous tombstones of the Old Jewish Cemetery in Prague has proved that it originates primarily from the sulfur pollution of the atmosphere.

10. Durability of Cement Mortars and Concretes. U. Ludwig. Durability of Building Materials and Components, ASTM STP 691, edited by P. J. Sereda and G. G. Litvan, American Society for Testing and Materials, 1980, pp. 269-281.

This paper presents the results of theoretical and experimental studies concerning the durability of cement mortars and concretes. The behavior of different cements in mortars and concretes which are exposed to attack by carbon dioxide in the atmosphere, sulfate ions or the alkali silica reaction (ASR) is described. The principal results which have been obtained during the past 10 to 15 years, also are summarized.

Carbonation of cement mortars and concretes follows a $\sqrt{t}$ relation. The increasing total lime content of mortars and concretes with portland cement together with the compaction of the microstructure due to carbonation leads to better durability of this type of cement as compared with cements of lower lime content.

The attack of sulfate solutions causes the initial cracking by topochemical ettringite formation which is followed by the formation of gypsum as a secondary reaction. The latter explains the often observed interim rehealing.

The alkali silica reaction (ASR) is considered as the result of dynamic osmosis equilibrium. The minimum relative humidity necessary for ASR is $80 < x < 85$ percent. The delayed ASR leads to an increased deterioration of the structure. Water repellent agents are suitable to prevent the ASR. Pozzolans and blast furnace slags in cements reduce or prevent the ASR. The maximum expansion forces are observed to be 1.7 N/mm^2 . The damages on buildings can be determined on drill-core samples.

11. Durability of Composite Materials as Influenced by Different Coefficients of Thermal Expansion of Components. S. D. Venecanin. Durability of Building Materials and Components, ASTM STP 691, edited by P. J. Sereda and G. G. Litvan, American Society for Testing and Materials, 1980, pp. 179-192.

Composite materials such as concrete usually are not composed of materials of the same coefficient of thermal expansion, and, therefore, temperature changes cause stresses in their components. In the paper, two simple equations are derived—one for tensile stress in binding material, and the other for tensile stress in aggregate. If coefficients of thermal expansion of aggregate and binder differ too much, large diurnal or seasonal temperature changes cause in portland cement concrete excessive tensile stresses in hardened cement paste, and in polymer concrete excessive tensile stresses in aggregate. So, for certain climatic conditions, and with known elastic and thermal properties of components, by using derived equations, it is possible to calculate tensile stresses in binder or aggregate, and estimate if they affect durability of concrete or some other material with two components. Typical applications of the derived equations are in the cases of the Middle East concretes or polymer concretes.

12. Durability of Materials and Construction. J. H. Keyser. Durability of Building Materials and Components, ASTM STP 691, edited by P. J. Sereda and G. G. Litvan, American Society for Testing and Materials, 1980, pp. 38-55. (Fe80-9)
13. Durability Studies at the Portland Cement Association. P. Kliegar. Durability of Building Materials and Components, ASTM STP 691, edited by P. J. Sereda and G. G. Litvan, American Society for Testing and Materials, 1980, pp. 282-300.

Durability studies at the Portland Cement Association over the years have included both laboratory accelerated tests and field exposure to service conditions in a variety of environments. Laboratory accelerated tests have included: freezing and thawing in water; resistance to application of de-icing chemicals during exposure to freezing and thawing; resistance to aggressive chemicals such as sulfates; alkali-aggregate

reactions; and corrosion of reinforcing steel. Field exposures have included: full-scale concrete pavements subjected to traffic and exposure to severe weather and deicers; simulated bridgedeck sections in outdoor exposure; concretes in sulfate soils; and concrete piles and other specimens in seawater. Some highlights of these studies are presented.

14. High Humidity Buildings in Cold Climates - A Case History. R. G. Brand. Durability of Building Materials and Components, ASTM STP 691, edited by P. J. Sereda and G. G. Litvan, American Society for Testing and Materials, 1980, pp. 231-238.

The masonry envelope over a steel structure in a 10-story building failed and had to be replaced after 17 years of service because of severe deterioration of some materials within the masonry walls. The building was designed for use as an office block but it was used for the display, servicing, and storage of art treasures for which the inside atmosphere was maintained at a temperature of 21°C (70°F) and 50 percent relative humidity the year round. The highly humidified air, in escaping through leakage paths in the building envelope, lost moisture by condensation which accumulated in and on the building materials. This led to the degradation of mortar, deterioration of masonry by frost action, and corrosion of metal ties and fasteners.

15. Is the Taj Mahal Doomed? Time, November 3, 1980, p. 99.

The Taj Mahal is another beautiful monument threatened with destruction by industrial pollution. Coal dust and sulfur dioxide fumes are the main destructive agents of the marble. No workable solution has been found yet.

16. Polluted Rain. Deterioration of Architectural Structures and Monuments. K. L. Gauri. Environ. Sci. Res., v. 17, 1980, pp. 125-145.

Weathering of carbonate and silicate minerals, essential constituents of natural stone, concrete, and mortar, which are the common materials exposed on the facades of architectural structures, has increased at an alarming rate in industrial countries because of NO₂ and SO₂ emissions.

17. Regional Air Pollution Study: Effects of Airborne Sulfur Pollutants on Materials. F. Mansfeld. NTIS Report PB81-126351, January 1980, 163 pp. (Fe80-18)

18. Rock Weathering at Archaeological Sites In Yucatan, Mexico. D. Dragovich. ICCM Bulletin, v. 6, No.1, 1980, pp.43-50.

In tropical lowland Yucatan, numerous sites relating to Mayan civilisation are being investigated and reconstructed by archaeologists.

All structures, stele and carved objects and decorations in the region have been made from locally-obtained limestone, which could be expected to weather principally by solution. Observations were made on the nature of weathering at three sites in Northern Yucatan and information was also sought on rates of weathering. Partly because of dating problems for individual structures or parts of structures, only isolated and incomplete evidence was obtained for weathering rates.

19. The Meaning of Durability and Durability Prediction. G. Frohnsdorff and L. W. Masters. Durability of Building Materials and Components, ASTM STP 691, edited by P. J. Sereda and G. G. Litvan, American Society for Testing and Materials, 1980, pp. 17-30. (Fe80-19)

20. Urban Pollution is Turning the Glory That Was Rome to Dust. H. Tanner. New York Times, March 16, 1980, p. 53.

Pollution and vibration from auto traffic are seriously damaging Rome's most famous monuments. Chemical reactions among rain water, auto exhaust fumes, and emissions from the city's heating plant are producing sulfuric acid that changes the calcium carbonate marble surfaces into calcium sulphate plaster. Damage to such monuments as the Column of Marcus Aurelius in the Piazza Colonna and the Arch of Constantine are reported. At the present rate of decay, virtually all the sculpture on these monuments will disappear within 20 years. Plans to reduce traffic in Rome are discussed.

21. Weather and the Deterioration of Building Materials. D. W. Boyd. Durability of Building Materials and Components, ASTM STP 691, edited by P. J. Sereda and G. G. Litvan, American Society for Testing and Materials, 1980, pp. 145-156.

Early attempts to predict the effects of the weather on the deterioration of building materials were often little more than speculation. The inadequacy of the results is discussed using freeze-thaw cycles and the annual driving rain index as examples. More precise empirical relationships will have to be based on laboratory or test-site observations and may require special weather analyses such as the humidity tables prepared for a study of corrosion of metals. More complex relationships are being found and the analysis of the weather often will involve the study of the coincident values of two or more elements. The research scientist should be aware of the weather data now generally available and the types of analyses that could be provided.

1979

1. Air Pollution Damage to Buildings on the Acropolis. J. E. Yocum. J. Air Pollut. Control Assoc., v. 29, No. 4, 1979, pp. 333-338.

The damage to the historical buildings in the Acropolis was surveyed. The damage was due to abrasion and chemical attack from air pollutants (SO_2 and SO_3).

2. Air Quality Related Values Study At Chaco Canyon National Monument. W.O. Herriman, B. Moore, M. C. Hugh, and K. A. Yarborough. 2nd Conference on Scientific Research in the National Parks, San Francisco, California, November 26-30, 1979, p. 134.

Chaco Canyon is an internationally significant area in which the National Park Service is preserving the ruins of the Pre-Columbian Chacoan culture. A detailed study has been undertaken to provide protection of the significant cultural and natural resources of Chaco Canyon.

3. Atmospheric Pollution and Biological Damage to Art Monuments. Methodological Proposals. S. B. Curri. *Acqua Aria*, No. 4, 1979, pp. 309-314 (Italian).

The biological factors, that is, microorganisms and biological molecules, and their interaction with physicochemical factors of the environment which affect works of art are enumerated and briefly discussed.

4. Biocide Testing and Enzymological Studies on Damaged Stone and Fresco Surfaces. Preparation of Antibigrams. S. B. Curri. *Biochem. Exp. Biol.*, v. 15, No. 1, 1979, pp. 97-104.

Samples of stone artifacts and fresco surfaces damaged from microbial attack were studied. To evaluate the microbial damaging process on the basis of biochemical analyses, the following areas were studied: 1) the relation between the entity of the microbial attack and enzymic activities inside the damaged substrate; 2) biochemical methods to evaluate the stone pollution; and 3) preparation of antibigrams to evaluate the action of some biocides.

5. Buildings Threatened by Air Pollution--Contribution of Material Research to the Preservation of Monuments. K. Niesel. *GIT--Fachzeitschrift fuer das Laboratorium*, v. 23, No. 2, 1979, pp. 105-109 (German).

By means of the X-ray scanning electron microscope the distribution of sulfur on the surface of building stones was analyzed. It was found that sulfur is only concentrated on the utmost surface, where a reaction with the calcium of the stone occurs. Laboratory techniques have been developed to simulate weathering in urban atmospheres and to study the behavior of weathered stone.

6. Corrosion Problems in Greece and the Contributions to Their Solution by the Laboratory of Physical Chemistry and Applied Electrochemistry of the

National Technical University of Athens. T. Skoulikidis. British Corrosion Journal, v. 14, No. 2, 1979, pp. 61-68.

The highly polluted and salt-laden atmosphere of Greece is discussed, in relation to damaging effects on metals, ancient monuments and statues. The marble statues are crusted with gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) if sheltered or pitted and cracked if exposed to rain. Bacteria and deposits of colloidal particles further destroy the marble and gypsum. Steel reinforcements, now corroded, are causing cracks in stonework, and titanium replacements are recommended. Chemical methods of converting gypsum to CaCO_3 are being developed; one employing CO_2 at eight atmospheres and 70°C is successful, provided the statues may be transported. Thirty types of protective coating were tried and rejected. Acetone-soluble biocides can be used but the particulate deposits cannot yet be removed.

7. Deterioration of Building Materials Due to Air Pollution and Soluble Salts. P. Berti. Proc. of the Symposium, Cini Foundation, (October 22-23, 1979), pp. 153-161 (Italian). (See MAC79-12 for symposium (proceedings)).

The damages caused by atmospheric pollutants: sulfates, nitrates, and chlorides is studied.

8. Effect of Acid Rain on Structures. K. L. Gauri. Symp. on Acid Rain, American Society of Civil Engineers, Preprint 3598, 1979, pp. 55-75.

The effect of acid rain on structures has been illustrated by the example of the deterioration of the exterior of the Field Museum of Natural History, Chicago. The field survey revealed that the marble cornices, etc., protected from the direct impact of rain has developed black crust. The unprotected areas, however, are clean due to perpetual dissociation of calcite grains. Fractures in marble blocks were found along dark bands which terminated at joints with polymeric caulking.

Atomic absorption spectrophotometry, scanning electron microscopy, and X-ray diffraction of samples from the museum revealed that the black crust consisted of gypsum which had formed due to SO_2 attack on calcite. The gypsum was absent at the naturally cleaned surface. By comparing these findings with the deterioration of marble at other antique structures, it has been concluded that the protected regions shall eventually suffer greater deterioration.

The conservation technology is yet in its incipient state. It is perhaps more economical to clean the air and save less deteriorated structures from meeting the fate that has visited the ancient marvels of architecture.

9. Efflorescences on Building Stones--SEM in the Characterization and Elucidation of the Mechanisms of Formation. A. E. Charola and S. Z. Lewin. Scanning Electron Microscopy, v. 1, 1979, pp. 378-386.

The mineral composition, texture, and structure of efflorescences on surfaces from a variety of sources are given. The seeping of water along

internal concrete or mortar surfaces produces deposits of calcite. Percolation of rain water through the bulk volume produces deposits which may contain trona, apthitalite, gypsum, and epsomite. Migration of salts from adjacent materials yields efflorescences of alkali sulfates, gypsum, and sodium chloride.

Scanning electron microscopic studies of the structure of efflorescent encrustations shows that crystal growth tends to occur preferentially at the substrate-to-efflorescences interface, with new crystals extruding previously formed crystals outward.

Some implications of the composition of efflorescences for the conservation and preservation of building stone are discussed.

10. Empirical Atmospheric Parameters - A Survey. T.A. McMahon and P.J. Denison. *Atmos. Env.*, v. 13, 1979, pp. 571-585.

Based on an extensive literature search, the following atmospheric deposition parameters have been collated and, where possible, generalized values have been noted: deposition velocity of particles, deposition velocity of gases, surface resistance to gaseous deposition, scavenging coefficient of particles, scavenging ratio and scavenging coefficient of gases.

11. On the Weathering of Building Materials in Atmospheres Containing Sulfur Oxides--A Literature Discussion. K. Niesel. *Fortschr. Miner.*, v. 57, No. 1, 1979, pp. 68-124 (German).

Numerous papers deal with the weathering of lime-containing building stones exposed to atmospheric sulfur oxides. The presences of such air pollutants is closely connected to the consumption of fossil fuels. Up to now it has only been possible to bring partial light upon aspects of the processes taking place during this type of action. Difficulties often result from the shortage of suitable methods to characterize quantitatively a rock and the changes in it by means of physical characteristic values, and also from the lack of a standard to which the data obtained may be compared. Of interest too is the question of how far artificial weathering results correspond to the actual behavior of the exposed rock on the outside of a building, and the question of how useful and reliable preservation measures are. Moreover, the role of media acting physically and chemically in the pore space are discussed, along with the phenomenological particularities of "weathering profiles" formed in the surface zone of the building stone as a result of attack by SO_2 . In this paper, an attempt is made to give as complete as possible a state-of-the-art report in this field, evaluating literature and using personal judgement in order to provide a basis for further investigations.

12. The Bricks of Venice. Status of Technical and Scientific Knowledge. Proceedings of the Symposium, Cini Foundation (October 22-23, 1979). Laboratorio per lo Studio Della Dinamica Delle Grandi Masse Del C.N.R. Venezia, 1979, 462 pp. (Italian).

The 33 papers presented at the symposium are presented in this preprinted edition. The main topics are: the brick material (history and technology), the deterioration processes, and the different conservation methods.

13. Two Cases of Sulfate Attack on Concrete. Y. Houst. Chantiers, No. 2, February 1979, pp. 15-18 (French).

The deterioration of concrete due to water and salts is briefly described. The resistance of various kinds of concrete and methods of mixing concrete that are resistant to the environment are discussed.

14. Use of Building Surfaces in the Passive Abatement of Gaseous Pollutants. H. S. Judeikis. J. Architectural Research, v. 7, No. 1, March 1979, pp. 28-33. (Fe79-10)

1978

1. A Methodological Approach to the Study of the Deterioration of the Statues in Boboli Garden (Pitti Palace - Florence) I. Analysis of Weather Variables. P. Frediani, C. Manganelli Del Fa, U. Matteoli, P. Tiano, and G. Galli. Proc. Int. Symp. on the Deterioration and Protection of Stone Monuments, Paris (June 1978), published by UNESCO and RILEM, No. 7-4, 1978, 24 pp.

In this research the effect of the treatment with a water repellent on a series of statues placed in the Boboli garden has been investigated. Temperature, relative humidity, wind direction and intensity, and sulfur dioxide concentration were measured at statues in three different exposures: a) sheltered in a grotto or in a niche; b) surrounded by vegetation; c) completely in the open.

In order to follow the efficiency of treatment, physical, mineralogical, microbiological, and chemical analyses before and after the treatment were performed. The results obtained seem to show the efficiency of this treatment in decreasing the humidity and microbiological contaminations of the surface of the statues. The decrease of efficiency of the treatment with time depends on the kind of stone and climatic variables.

2. A Review: The Lichen Role in Rock Art - Dating Deterioration and Control. M. L. E. Florian. Conservation of Rock Art, edited by C. Pearson. ICCM, 1978, pp. 95-98.

The role of lichens in rock art, including the deterioration they cause and the question of their removal with reference to damage of rock surface, aesthetic considerations, and the type of lichen attachment is described. The possible use of lichenometry for dating rock art is also discussed.

3. A Survey on Air Pollution and Deterioration of Stonework in Venice.
V. Fassina. Atmos. Environ., v. 12, No. 11, 1978, pp. 2205-2211.*

The effects of atmospheric pollutants on the deterioration of stonework in Venice was studied during 1972-74 by measuring aerosol composition and HCl and SO₂ concentrations. Aerosol acidity, sulfate particulate matter, and SO₂ concentrations showed seasonal variations; that of SO₂ being the most significant due to variations in meteorological conditions and urban and industrial output. Microscopic and microchemical analysis of the stonework showed crack formation to occur by two processes; penetration by H₂SO₄-containing solutions and by NaCl and crystallization of soluble salts.

4. Acid Precipitation in the Netherlands. A. J. Vermeulen. Environ. Sci. Tech., v. 12, No. 9, September 1978, pp. 1017-1021. (Fe78-1)
5. Acid Rain Fallout: Pollution and Politics. J. Gannon. National Parks and Conservation, v. 52, No. 10, October 1978, pp. 17-22.

Acid rain kills fish, stunts plants, and corrodes buildings. Acid rain has wiped out commercial salmon fishing in Norway and Sweden and has destroyed sport fishing in parts of Canada, the United States, and Scandinavia. The burning of fossil fuels and the smelting of ores produces sulfur and nitrogen oxides, which are converted to acids in the atmosphere. The problem of acid rain is transnational and transcontinental. There is a high correlation between acid levels in lakes and mercury levels in fish. Acid rain, mercury pollution, and the construction of a new coal-fired power plant threaten the existence of an Ojibway Indian fishing village on Lac la Croix in Quebec, Ontario. Governmental efforts to control acid rain are insufficient.

6. An Experience From the Restoration of the Exposed Stone, Palace Madame of Turin. M. G. Cerri. Proc. Int. Symp. in the Deterioration and Protection of Stone Monuments, Paris (June 1978), published by UNESCO and RILEM, No. 7-2, 1978, 27 pp.

The history of the monument is first presented to demonstrate its value. The researches have shown that the main cause of degradation is the sulfation due to sulfur dioxide present at very high concentrations in the atmosphere, in connection with the high humidity of the cold season. Cleaning by water or by jets of vapors at low pressure to dissolve surface salts has brought the stone to optimal condition for application of protective siliconic resins.

7. Atmospheric Pollution in Venice, Italy, as Indicated by Isotopic Analyse
A. Longinelli and M. Bartelloni. Water, Air, Soil Pollut., v. 10,
No. 3, 1978, pp. 335-341.*

Rainwater samples collected in Venice over a period of about 1 year were studied along with stone samples collected from buildings and

monuments. Isotopic measurements of oxygen, sulfur, and carbon were carried out on rainwater, rainwater dissolved sulfate, carbonate in stone and sulfate present in altered limestone, with the purpose of proving that atmospheric pollution is mainly responsible for the deterioration of monuments and buildings. Atmospheric sulfate in Venice is basically tied to the emission of anthropogenic SO_2 and only minor contributions can be expected from seawater spray and aerosols. The measurements carried out on stone samples clearly indicate that stonework is damaged by the interaction between limestone and sulfur-bearing atmospheric pollutants.

8. Characteristics and Decay of Stone Materials Used in Ca' Granda (The Old Hospital of Milan Building). R. Peruzzi, G. Giambelli, L. De Capitani G. Alessandrini, and G. Liborio. Proc. Int. Symp. on the Deterioration and Protection of Stone Monuments, Paris (June 1978), published by UNESCO and RILEM, No. 1-5, 1978, 20 pp.

The characteristics and the causes of decay of three types of stones taken from "Ca' Granda" in Milan have been examined before undertaking a study of their conservation. Chemical, mineralogical, petrographical, physical, and structural analyses have been performed on samples taken from the monument and from the quarry. The characteristics of the stones have been compared and then correlated with their state of conservation. The alteration products (crusts, efflorescences) have also been analyzed and measurements have been taken of the environmental temperature and relative humidity, the surface temperature of the monument, the ambient concentration of SO_2 , and the SO_4^{2-} , NO_3^- and pH of rain samples.

9. Corrosion Protection of Ancient Marble. G. M. Schwab. VDI-Ber., v. 314, 1978, p. 101 (German).

The corrosion of ancient marble in Athens has been greatly accelerated by the increased levels of sulfur compounds in the modern atmosphere, thereby increasing the damaging effects of rainfall. In addition to surface breakdown, pollution increases the rusting of iron supports and reinforcements which can result in further breakup of the marble. A number of measures have been suggested, including the placing of objects in museums, restrictions on atmospheric levels of sulfur compounds, investigations of surface treatments, and replacement of iron reinforcements with titanium ones.

10. Decay and Protection of Stones in Historical Buildings of the University of Pavia (Italy): V. Riganti, R. Rossetti, F. Soggetti, F. Veniale, and U. Zezza. Proc. Int. Symp. on the Deterioration and Protection of Stone Monuments, Paris (June 1978), published by UNESCO and RILEM, No. 7-20, 1978, 10 pp.

The state of degradation of materials (granites of Baveno and Montorfano; marble of Candoglia, Irnavasso and Crevola, rocks of Angera, Viggiu and M. Anzolo), of lithic structures (columns, balustrades, portals and more important pronaos) realized from the 15th to the 19th century in two historical monuments of the University of Pavia: the main palace of

the atheneum and the ensemble of buildings of the old convent of San Felice. The predominant alteration of the lithic carbonaceous materials (calcitic and dolomitic marble, dolomite, oolitic limestone) and of the limestone with calcitic cement, is due to the gradual transformation of carbonates into gypsum which, because of the correlative multiplication, caused the desegregation and separation of degraded parts under the action of sulfurous gas present in urban atmosphere. It is observed in the granites an alteration due mostly to humidity and which develops on the "rift" surface. Remedies for protection have been proposed.

11. Descriptive Characterization of the Grain Textures, Mineralogy, Density and Structures of Ornamental and Building Stones Such as Carrara Marble, Istrian Stone, Greek Marble, Valpolicella Stones, San Giulian Marble (Pisa), and Their Reactivity With Sulfur Dioxide. R. D. Harve International Biodegradation Research Group, Autumn Meeting, Winchester (October 18-20, 1977), Editore Poligrafico Artioli, Modena, Italy, 1978, 10 pp.

Describes methods and research concerning building stone listed in the title. Source, rock type, color, petrography and mineralogy, including bulk density and porosity for each stone tested, are given. The source of at least some of the sulfur that is so damaging to works of art is the limestone itself.

12. Deteriorative Effect of Sulfur Pollution on Materials. J. O. Nriagu. Sulfur in the Environment, Part II: Ecological Impacts, edited by J. O. Nriagu, Wiley, New York, N.Y., 1978, pp. 1-59. (Fe78-11)
13. Inspection of Bioaggression on a Statue of Carrara Marble of 700(A.D.) From the Hill Country. A. Paleni, S. B. Curri, and R. Benassi. International Biodegradation Research Group, Autumn Meeting, Winchester (October 18-20, 1977), Editore Poligrafico Artioli, Modena, Italy, 1978, 21 pp. (Italian).

Bioaggression occurred on a statue of Carrara marble (700 A.D.) placed in a garden at the top of a hill by the sea. Photo enlargements show lichens covering part of the surface. Placodium, xanthoria parietina, vitellina, physcia grisea, and lecydia were identified in the lichenic tissue, as were bacteria up to 2,000,000 colonies per gram, fungi up to 1,000,000 per gram, yeast up to 800,000 colonies per gram. Thioxidans and thioparus to 1,000,000 colonies per gram were identified on the surface of the statue, which was seemingly undamaged. Photos show the surface of the statue; micromorphology of marble grain texture, mineralogy, and petrography are reported. Incipient formation of a black crust is described. Thin layer chromatography identified some lipids on the surface of the statue as alpha and beta monoglycerides, diglycerides, triglycerides and sterol-ester of bacterial origin. Estimates are given on future bioaggression.

14. Investigation of Weathering Crusts on Salzburg Stone Monuments. E. Hoke
Studies in Conservation, v. 23, 1978, pp. 118-126.

A series of corroded stone specimens from Salzburg monuments was examined by electron-probe microanalysis. The crusts arose from environmental effects, in the case of marble primarily from SO_2 . Deterioration phenomena can be correlated with stone surface features.

15. Laboratory Measurements of Nitric Oxide and Nitrogen Dioxide Depositions
Onto Soil and Cement Surfaces. H. S. Judeikis and A. G. Wren. Atmos.
Environ., v. 12, No. 12, 1978, pp. 2315-2319.

The deposition rates of NO and NO_2 onto soil and cement surfaces were approximately 0.1 to 0.2 and approximately 0.3 to 0.8 cm/s respectively. Deposition was irreversible and decreased with time. However, surface activity was restored by precipitation washing away solution surface reaction products or, for NO_2 -saturated surfaces, by interaction with NH_3 . Nitrogen dioxide deposition on ground level surfaces is the predominant mechanism for $\text{NO} + \text{NO}_2$ removal from the atmosphere in both urban and remote areas.

16. Microecology, Mineralogy and Alteration of Works of Art: St. Mark's of
Venice and The Cene of Milan. C. Jeanson. Proc. Int. Symp. on the
Deterioration and Protection of Stone Monuments, Paris (June 1978),
published by UNESCO and RILEM, No. 5-4, 1978, 15 pp. (French).

The crystals in formation on the altered surface of the crest of the facade of St. Mark's are compared with those at the base of a wall painting named "La Cene" by Leonardo De Vinci. Studies with the EMA and by SEM EXORA permit identifications of sulfates and carbonates. Evidence of The relation between these salts and microorganisms is presented. Recent mineralizations, weathering crusts, are put in a microecologic context.

17. Microorganisms and Weathering of a Sandstone Monument. F. E. W. Eckhardt.
Environ. Biogeochem. Geomicrobiol., Proc. 3rd Int. Symp. (1977),
edited by W. E. Krumbein, Ann Arbor Sci., Ann Arbor, Michigan, 1978,
v. 2, pp. 675-686.

Weathering of a sandstone monument in Kiel, Federal Republic of Germany, was affected by microorganisms which enhanced the deterioration of both cementing material and the aluminum silicates by producing organic acids, for example, oxalic acid and citric acid. Fungi were the predominant microorganisms found on the stone.

18. Progress and Problems in Rock Weathering Related to Stone Decay.
W. D. Keller. Decay and Preservation of Stone: Engineering Geology
Case Histories, No. 11, edited by E. M. Winkler, Geological Soc. of
America, 1978, pp. 37-45.

This survey article describes weathering phenomenon in general. Also discussed are the effect of aqueous solutions, CO_2 , O_2 , temperature, etc. on chemical weathering, especially of aluminum silicate minerals and carbonate rocks such as limestone, dolomite and carbonate cemented clastic rocks.

19. Proof of the Activity of the Thiobacillus in the Alterations of Stones at Rome. Identification of Certain Sources. L. Barcellona-Vero. Proc. Int. Symp. on the Deterioration and Protection of Stone Monuments, Paris (June 1978), published by UNESCO and RILEM, No. 4-1, 1978, 13 pp.

Microbiological analysis of stone sample from six monuments in Rome (marble, traventine, tufa) are reported. Nitrogen bacteria were found in half the samples; sulfur reducing bacteria were absent, thiobacillus strains were present in most of the samples. Research points out the necessity of preparing cultures for both sulfur and thiosulfate bacteria.

20. Recent Experience in Conservation of Stone Objects. J. Lehmann. Proc. 5th Meeting ICOM Committee for Conservation, Zagreb, 1978, pp. 1-6.

At its 4th Triennial Meeting in Venice-1975, the Working Group "Stone" has accepted the modified program developing activities in the conservation of stone objects in museums, collections, and from excavations. Consideration is also devoted to preserve outdoor objects and to consolidate decayed stone.

The activities and accomplishments of the Working Group "Stone" are reported on the background of international developments in stone conservation during past three years. They are concerned mainly with complex conservation of valuable artistic and historic stone objects, consolidation of decayed stone, desirable characteristics of chemicals used in conservation of stone objects, protection of stone by means of water-repellency and organic surface layers, polymer coatings used for cleaning of dirty and stained surfaces of stone, mathematical models for computation and the device for measurement of weathering rates of stone as well as documentation and inspection of treated stone objects.

21. Research on Surface-Conservation of Corroded Pentelich Marble of the Acropolis in Athens. D. D. Klemm and R. Snethlage. Proc. Int. Symp. on the Deterioration and Protection of Stone Monuments, Paris (June 1978), published by UNESCO and RILEM, 1978, p. 9.

Investigations of deteriorated Pentelich marble show a typical type of corrosion, by which the crystals themselves are dissolved to skeletons, whereas the intergranular spaces are only slightly widened. Corrosion tests on impregnated Pentelich marble samples show that the methacrylic resin used does not prevent the growth of gypsum after the sulfuric acid attack.

22. Researches on the Deterioration of Stonework. VI. The Donatello Pulpit. R. Franchi, G. Galli, and C. Manganelli Del Fa. Studies in Conservation, v. 23, February 1978, pp. 23-37.

The state of deterioration of Donatello's Pulpit at Prato Cathedral was studied. Analytical data obtained show that its present condition is due both to natural causes of alteration which affect a sculpture standing for a long time in the open and to products used for restoration and conservation in fairly recent times. These products have caused reactions with the stone material and formed new mineralogical species which have been detected at moderate depths. They have also been a determining factor contributing to decohesion of the granules of the stone and hence to an increase in the specific surface, with consequent acceleration of the phenomena of alteration.

23. Rock Weathering on the Molecular Level. P. P. Hudec. Decay and Preservation of Stone: Engineering Geology Case Histories, No. 11, edited by E. M. Winkler, Geological Soc. of America, 1978, pp. 47-50.

Based on measured physical properties and internal surface area of 26 rock specimens, internal surface area and average pore size have been shown to be directly correlatable to the response of a rock to weathering. The weathering action begins at the surface of the rock pore by the adherence of the water molecule (and other ions of salts) to the surface. The water becomes polarized by the surface, similar to the polarization of water around a clay particle, which is well documented in literature on soil-water interaction. The water is physically rigid and tends to exert pressure against the pore walls. Because of the polarization of the water and the high concentration of hydrogen ions at the surface, the surface becomes hydrolyzed, and the internal rock surface is chemically attacked. Large surface area promotes rapid rock deterioration. The Physical breakdown of rocks with large internal surface area predominates in cooler climates because of the pressures generated by the rigid water films. In the more tropical regions, hydrolysis is probably the principal process that is aided by the physical breakdown.

24. Scanning Electron Microscopy in the Diagnosis of "Diseased" Stone. S. Z. Lewin and A. E. Charola. Scanning Electron Microscopy, v. I, 1978, pp. 695-704.

Exposed stone and masonry deteriorate in a variety of ways, depending upon the chemical reactivity, grain size and texture, porosity, and degree of induration. Scanning electron microscopy (SEM), employed in conjunction with X-ray diffraction, optical microscopy, and chemistry, discloses the internal structure and texture of the stone, as well as the presence of adventitious substances and, hence, is effective in elucidating the susceptibility to, and state, of decay and its causes in specific cases.

Limestones and marbles show significant direct solubility in environmental water, as well as enhanced solubility due to chemical reaction with air pollutants. Water-soluble materials either produced in the stone or carried into it from adjacent sources deposit in cracks and pores at the surface as the stone dries and generate pressures that break

down intergranular attachments and cause the stone to crumble, crack and exfoliate.

Quartzite and arkosic sandstones deteriorate principally under the influence of the stresses accompanying freeze-thaw and wet-to-dry cycling. Slates suffer delamination; zeolitic stone is subject in addition to specific effects of a chemical nature.

Synthetic resin-powdered stone composites used as a replacement for decayed natural stone tend to fail because of the crystallization effects that occur along shrinkage crevices in the resin layer. The micrographs presented show the application of SEM in characterizing the type of stone present and its condition in specific monuments, as well as in identifying the principal mechanism responsible for the manifestations of decay.

25. Some Problems Raised by the Study of the Weathering of Igneous Rocks.

J. D. Rodrigues. Proc. Int. Symp. on the Deterioration and protection of Stone Monuments, Paris (June 1978), published by UNESCO and RILEM, 1978, 16 pp.

The weathering of rocks used for buildings of historical or artistic interest has prompted numerous studies on the weathering mechanisms and on the methods of stone conservation. Analysis of papers published shows that non-igneous rocks are those most referred to by researchers. In the present work some considerations are made about the use of the different types of rocks for study and research in the domain of stone weathering and conservation. Important differences of composition and behaviour between sedimentary and igneous rocks are pointed out, and some relevant and specific aspects of the study of the latter rocks are described. Emphasis is laid upon the need for this type of rock to be systematically used in comparative studies of test methods and conservation treatments.

26. Stone Decay in Tropical Conditions--Treatment of Monuments at Khajuraho, M.P., India. B. R. N. Sharma. Proc. Int. Symp. on the Deterioration and Protection of Stone Monuments, Paris (June 1978), Published by UNESCO and RILEM, 1978, No. 7-19, 11 pp.

This paper describes the stone decay as observed by the author in India during the last 25 years. The monuments of stone (of various compositions) have been exposed to differing climatic conditions and the decay is described. Heavy industrialization has polluted the environmental condition of some monuments and the consequent decay has been shown. The phenomena of biodeterioration on the monuments has been explained. The last part describes the chemical treatment of monuments at Khajuraho and the problems tackled are explained.

27. Stone Decay in Urban Atmospheres. E. M. Winkler. Decay and Preservation of Stone: Engineering Geology Case Histories, No. 11, edited by E. M. Winkler, Geological Soc. of America, 1978, pp. 53-58.

There is evidence that damage to stone by different types of weathering is much more severe in urban environments than in rural. Action by moisture and salt in urban areas resembles conditions found on desert floors, the most destructive type of weathering. The elimination of street salting in cities, especially near masonry walls and monuments, and the sealing of potential travel routes for moisture would reduce most of the urban weathering to about the same as the weathering in rural areas. However, the present rate of increase of sulfate and CO_2 in the atmosphere is expected to accelerate weathering rates, urban and rural alike, especially dissolution, regardless of precautions taken in the future by conservators of historic buildings and monuments.

28. Stone Preservation of Cologne Cathedral. A. Wolff. Naturwiss. Rundsch, v. 31, No. 12, 1978, pp. 449-503 (German).

Many different types of stone were used during the long construction of the Cologne Cathedral, with the result that greatly differing degrees of weathering are apparent in the structure. The damage varies from simple color changes to severe deterioration of the stone. The effects of air pollution (especially sulfur compounds) on this destruction are discussed, as are recent attempts to preserve the stones of the cathedral.

29. Stone Weathering: A Literature Review. E. M. Winkler. Decay and Preservation of Stone, Engineering Geology Case Histories, No. 11, edited by E. M. Winkler, Geological Society of America, 1978, pp. 59-61.

The decay of building and decorative stone has caused concern for centuries. Frost, solar radiation and the presence of salts are instrumental in the mechanical destruction of rock and stone. The processes of chemical weathering consist of the relatively simple dissolution of carbonates and the very complex solubilization of silicate minerals. The penetration of hydrogen ions into the crystal lattice appears to be the most destructive factor in the weathering of the feldspars. Microbial life often invades masonry and is a significant deteriorating factor.

30. Study of the Absorptive Properties of Atmospheric SO_2 on Limestone Materials. P. Degranges, J. Greffard and J. M. Prevosteau. Proc. Int. Symp. on the Deterioration and Protection of Stone Monuments, Paris (June 1978), published by UNESCO and RILEM, 1978, 19 pp. (French).

Laboratory simulation of aggressive atmospheres to study the sorption process of marble showed that some SO_2 is sorbed at an elevated energy state. The relationship established between sorption properties and porosity indicates that marbles of low porosity will withstand urban environments.

31. Study of the Reactions Between Gaseous Sulfur Dioxide and Calcium Carbonate. M. Serra and G. Starace. Proc. Int. Symp. on the Deterioration and Protection of Stone Monuments, Paris (June 1978), published by UNESCO and RILEM, No. 3-7, 1978, 19 pp.

A study was made of the reactivity of sulfur dioxide with calcium carbonate in a heterogeneous phase. The results show that the quantity of sulfur dioxide absorbed and transformed in the oxidized phase is dependent upon the relative humidity and the characteristics of the surfaces tested.

A chamber study of the reactivity of sulfur dioxide with calcium carbonate indicates that SO_2 is not only absorbed in relatively high quantities by the CaCO_3 , but that it reacts partially and/or totally with the CaCO_3 , being transformed into calcium sulfate. The rate of absorption and transformation to an oxidized state depends on the relative humidity and on the characteristics of the surfaces tested. The oxidation catalysis is shown to be strictly dependent on the presence of water. On the other hand the characteristics of the surface play an important role as they accelerate the processes of absorption and oxidation under the same conditions of relative humidity.

The mechanism described is essentially concerned with the surface aspects of the reaction which, under real conditions, can be the cause of corrosion even in deeper layers of the materials by diffusion of SO_2 through fractures and pores. Although the calcium sulfate which has been formed is inert with regard to SO_2 , it has no protective action as it does not form a uniform and coherent layer with the underlying CaCO_3 , and in the presence of water it dissolves.

The relative importance of the direct reaction of SO_2 with CaCO_3 in comparison to the reaction by SO_2 in an aqueous solution obviously varies according to the climatic conditions and more precisely according to the microclimate around the exposed material. This reaction represents, however, the predominant mechanism in the absence of rain and when environmental humidities do not permit surface condensation.

32. Tests on Limestone Weathering. E. Orcsik, M. Zador, and T. Varga. Proc. Int. Symp. on the Deterioration and Protection of Stone Monuments, Paris (June 1978), published by UNESCO and RILEM, No. 1-4, 1978, 15 pp.

The weathering of limestone had been tested under different environmental (physical and chemical) conditions and in different biological expositions. The weathering process has been evaluated by scanning electron microscopy, by electron microprobe analysis and by infrared spectroscopy. Morphological and chemical tests showed the purely physiochemical weathering process to be qualitatively identical under different atmospheric pollutions, featured essentially by the transformation of calcite to gypsum. The atmospheric sulfur dioxide differing by orders of magnitude $.01 \text{ mg/m}^3$ and 0.10 mg/m^3 causes quantitative differences partly in the weathered thickness, partly in the percentage rate of surface sulfation. Presence of biological agents alters the weathering process, manifested partly by the different crystalline water modification of gypsum and partly by the increased rate of metabolites (chlorine, magnesium, potassium) in the surface

layers of stone, contributing to the degradation process. According to the element analysis, the stone surface incorporates significant quantities of magnesium, potassium and chlorine under the moss, while nothing but chlorine was found under the algae. No stone surface underlying any biological agent contained sulfur.

33. The Changing Chemistry of Precipitation and Its Effects on Vegetation and Materials. E. B. Cowling and L. S. Boehinger. Control and Dispersion of Air Pollutants, Emphasis on NO_x and Particulate Emissions, edited by R. L. Byer, D. W. Cooper, and W. Light. American Institute of Chemical Engineering Symposium, v. 74, No. 175 September 1978, pp. 134-142. (Fe78-16)

34. The Micro-Erosion Meter: Its Application to the Weathering of Rock Surfaces. D. I. Smith. Conservation of Rock Art, edited by C. Pearson, ICCM, 1978, pp. 44-53.

The Micro-Erosion Meter was developed about 1970 in order to obtain absolute measurements of rock lowering. The instrument is relatively cheap to construct and consists of an engineering micrometer dial gauge, with measurement probe, bolted onto a tripod framework. The legs rest on stainless steel studs which are permanently inserted into the rock surface. The legs are constructed to allow exact relocation of the meter so that initial and subsequent measurements can be compared after a period of months or years. The construction and method of use of the MEM is described with particular reference to the measurement of the weathering rock art.

35. The Non-Destructive Investigation of Chemical Alterations in the Surface of Stone. J. Sramek. Proc. Int. Symp. on the Deterioration and Protection of Stone Monuments, Paris (June 1978), published by UNESCO and RILEM, No. 2-8, 1978, pp. 1-14.

Reflection infrared spectroscopy was used for determining chemical compounds and their transformations within the stone surface. By means of this method chemical changes in the surface of gaize (cretaceous marly limestone) taking place after the application of freezing cycles and interaction with sulfur dioxide were studied. The tests proved that freezing caused irreversible losses of crystal water. The experiments with SO_2 showed that calcium carbonate is transformed into sulfate by two different mechanisms, strongly dependent on the stone water content.

36. The Preservation of Stone. K. L. Gauri. Scientific American, v. 238, No. 6, 1978, pp. 128-136.

Various building materials and the effects of urban pollutants and methods of preserving building materials are discussed.

37. The Problem of the Erosion of Stone and Methods for Its Evaluation.
O. L. Katsitadze and T. V. Iakashvili. Proc. 5th Meeting ICOM Committee for Conservation, Zagreb, 1978, 78/10/9, pp. 1-8.

Experiments in the theoretical mathematical investigation of stone erosion using many variables and statistical methods are described. Among the variables considered are acoustic wave velocity, air speed, air temperature, relative humidity of the air, precipitation, barometric pressure, duration of exposure, latitude, frequency of seismic oscillations, amplitude of seismic oscillations, duration of seismic events, elastic wave speed in the material, duration of erosion, material surface slope in relation to horizon, surface azimuth in relation to ground, yield stress of the material, ultimate resistance of the material, biological corrosion indices, chemical corrosion indices.

38. Warning for Wiligelmo Sculpture at Modena Cathedral of XIth Century.
A. Paleni and S. B. Curri. Int. Biodegradation Research Group, Autumn Meeting. Winchester (October 18-20, 1977), Editore Poligrafico Artioli, Modena, Italy, 1978, 14 pp. (Italian).

The presence of *Thiobacillus thioparus* on the surface of Wiligelmo sculptures at Modena Cathedral (1,000,000 colonies per gram of stone) is shown.

39. Weathering and Preservation of Stone Monuments Under Tropical Conditions: Some Case Histories. B. Lal. Proc. Int. Symp. on Deterioration and Protection of Stone Monuments, Paris (June 1978), published by UNESCO and RILEM, No. 7-8, 1978, 36 pp.

The problems of weathering and preservation of selected stone monuments situated in different regions of the Indian Sub-Continent have been discussed. The study of physical parameters, meteorological data, petrographical examination and chemical analysis of fresh and weathered rock samples have given some insight into the mechanism of degradation of such stone structural monuments and historical buildings as the Sun temple at Konark, the Shere Temple at Mahabolipuram, temples at Belur and Halebid, and the temples at Veraval and Dwarka. The rock-cut cave temples at Ajanta, Ellora, Elephanta, Jogeshwari, Karla and Bhaja have been subjected to detailed investigations for understanding the causes of their deterioration. Both physical disintegration and chemical weathering are in progress. Some of the chemical processes causing deterioration of stone monuments are: hydrolysis, carbonation, oxidation, and solution. Kaolinization, limonitization, gypsumization, chloritization, and Lateritization have been found to be proceeding in situ under the ambient environmental conditions. Destructive effects of sea-salts, sand-blasting action of dust-laden winds, and the degrading influence of cryptogamic growths have been recognized. In the absence of data on the bacterial degradation of stone in India, the role of bacteria in rock weathering remains unelucidated.

40. Weathering in Sandstone Shelters in the Sydney Basin and the Survival of Rock Art. P. J. Hughes. Conservation of Rock Art, edited by C. Pearson, ICCM, 1978,* pp. 36-41.

Reports on some of the findings of a recently completed study of the geomorphological histories of a number of sandstone shelter archaeological sites in Southern New South Wales. Average natural rates of cavernous weathering in these shelters was demonstrated to have been slow, on the order of 0.1 to 0.5 mm per 100 years, with granular disintegration and small-scale flaking being the main process at work. Man was shown to have greatly accelerated cavernous weathering and roof-fall by dislodging weathered rock and hence exposing fresh rock surfaces to further weathering, and by influencing the shelter environment through changes in temperature and humidity. Since abandonment, crusts of weathered rock have again formed on the roof and walls of most shelters and contemporary rates of weathering and roof-fall are again slow. The significance of cavernous weathering of such sandstone shelters for the age of deterioration of rock art are considered and plans to monitor sandstone weathering in a range of environments over a long time-span are outlined.

1977

1. A Series of Temporal Measurements of Particulates and Sulfur Dioxide in Venice. V. Fassina. Inquinamento, v. 19, No. 4, 1977, pp. 35-41 (Italian).

The amounts of SO_2 , Cl^- , SO_4^{-2} and of particulate matter, the causes of the destruction of Venice's architecture, were studied from January 1972, to December 1973. In most cases pollution is higher in winter than in summer.

2. Acropolis: Threat of Destruction. Time, January 31, 1977, p. 55.

The Acropolis, having resisted erosion and human assailants for 2,400 years is threatened to be destroyed by industrial air pollutants, especially sulfur dioxide which rapidly corrodes the marble. Several plans will be carried out to save the magnificent monument.

3. Alteration of Structural Stones in Venice: Action of Atmospheric Sulfur on Carbonate Rocks. A. Altieri, R. Funiciello, E. L. Palmieri, E. Lupia, and G. M. Zuppi. Ann. Ist Super. Sanita., v. 13, No. 1-2, 1977, pp. 331-342 (Italian).

Weathering of the facades on the Papadopoli Palace in Venice, which was built with a calcareous stone, was studied. Isotopic analyses showed the presence of several forms of CaSO_4 . Sulfur originated from the sulfates in seawater, SO_2 from the combustion of hydrocarbons, and H_2S evolved by organic substances that foul the canals. Climatic conditions play a significant role in the alteration of the stone, especially in the autumn and in the winter.

4. Causes for Corrosion and Methods for Hardening Sedimentary Rocks.
J. Zelinger and P. Kotlik. Chemické Listy, v. 71, No. 8, 1977,
pp. 838-863. (Czech)

The causes of corrosion of sedimentary rocks, especially of sandstone, are discussed. The problem of marble and arenaceous marl is also briefly mentioned.

5. Conference on Concrete in Aggressive Environments. Concrete Society of Southern Africa, Pretoria, South Africa, (October 18-19, 1977), Concrete Society of Southern African, Johannesburg, 1977.

Subjects discussed include concretes, reinforced concrete, corrosion, water corrosion resistance, corrosion protection, heating, cooling, surface finishing, cracks, stresses, strains.

6. Effects of Sulfur Dioxide on Materials. S. K. Gajendragadkar. Chem. Age India, v. 28, No. 8, 1977, pp. 673-677. (Fe77-5)
7. Effects on Economic Materials and Structures. J. E. Yocom and J. B. Upham. Chapter 2 in Air Pollution, edited by A.C. Stern, Academic Press, New York, N.Y., v. 2, 1977, pp. 65-116. (Fe77-6)
8. Guide to Durable Concrete. Committee Report. Committee 201, American Concrete Institute, Detroit, No. 74-53, December 1977, 37 pp.

Chapter 2, "Aggressive Chemical Exposure", summarizes research on sulfate attacks and acid attack. There are apparently two chemical reactions involved in sulfate attack on concrete.

1. Combination of sulfate with free calcium hydroxide (hydrated lime) liberated during the hydration of the cement, to form calcium sulfate (gypsum).
2. Combination of gypsum and hydrated calcium aluminate to form calcium sulfoaluminate (ettringite).

Both of these reactions result in an increase in solid volume. The latter is generally blamed for most of the expansion and disruption of concretes caused by sulfate solutions.

In addition to the chemicals reactions, Tuthill and Reading cite evidence that a purely physical action (not involving the cement), crystallization of sulfate salts in the pores of the concrete, can account for considerable damage. Reading also found that where heavy sections are exposed to a strong sulfate solution on the backside, most of the damage is confined to the outer surface adjacent to leaking joints and cracks.

In general, portland cement does not have good resistance to acid attack, although weak acids can be tolerated. The deterioration of concrete by acids is primarily the result of reaction between these chemicals and the calcium hydroxide of the hydrated portland cement. In most cases the chemical reaction results in the formation of water-soluble calcium compounds which are then leached away by the aqueous solutions.

Oxalic and phosphoric acid are exceptions, because the resulting calcium salts are insoluble in water and are not readily removed from the concrete surface.

9. How the Acropolis Can Be Saved. C. Bouras. UNESCO Courier, v. 30, Oct. 1977, pp. 4-11.

The increase in stone deterioration, that has occurred at the Acropolis over the last forty years and the actions being taken to reduce deterioration are discussed.

10. Measurement of Some Atmospheric Pollutants Taken in Venice Between Two Stations on a Vertical Scale. V. Fassina. Inquinamento, v. 19, No. 6, 1977, pp. 53-58 (Italian).*

Sulfuric acid, hydrochloric acid, sulfate, and chloride atmospheric pollutants caused deterioration of building stone in Venice, Italy.

11. Reactivity of Treated and Untreated Marble in Carbon Dioxide Atmospheres. K. L. Gauri, P. Tanjaruphan, M. A. Rao and T. Lipscomb. Trans. Kentucky Academy of Science, v. 38, 1977, pp. 38-44.

Marble specimens were impregnated with certain epoxies and fluorocarbon-acrylic copolymers. The treated and untreated specimens were exposed to, while immersed in deionized water, 0.983, 6.2, 8.28, and 11.02 percent pCO_2 at 20°C in a dynamic system. The concentration of leached Ca^{2+} in the water was determined by EDTA titrations and atomic absorption. The values obtained by those methods were nearly identical. The rate of reaction was based on the increment in Ca^{2+} concentration as a function of time. The equilibrium constant K , calculated from the experimental data, had a value of 1.49×10^{-6} , and compared well with the value of 1.58×10^{-6} given by Garrels and McKenzie. Specimens treated with fluorocarbon-acrylic compounds revealed only one-half reactivity relative to untreated specimens in the initial phases of reaction. Certain epoxies provided protection, other epoxies actually enhanced the rate of reaction. It is proposed that pertinent data generated in the course of this study be used as a basis for quantitative performance criteria for stone and concrete preservative treatments.

12. Research on Atmospheric Pollution in the City of Prato and on the Degradation of Stone Materials. A. Desideri and E. Piccardi. Inquinamento, v. 19, No. 5, 1977, pp. 41-44. (Italian)*

Air samples were taken daily from December 1975 through April 1976 in various sections of the historic center of Prato, Italy, to measure concentrations of HCl , SO_2 , and nitrogen oxides. Values for HCl varied

from 0.2 to 0.5 mg/m³ in all sections during the period while SO₂ concentrations averaged 0.02 to 0.2 mg/m³. Analyses also were made of stone building materials from the facade of St. Francis' church to determine Cl⁻ and SO₄⁻² content with a view to establishing a possible relation between deterioration of the building and presence of HCl and SO₂ in the atmosphere.

13. Stone Deterioration at the Cologne Cathedral and Other Monuments Due to Action of Air Pollutants. S. Luckat. Proc. 4th Int. Clean Air Congr., 1977, pp. 128-130.

Air pollutants, especially SO₂, contribute extensively to stone damage on the Cologne Cathedral. Sulfur dioxide uptake rates are higher in winter and increase with increasing elevation and wind speed. Stone damage correlates well with SO₂ uptake.

14. Stone Preservatives: Methods of Laboratory Testing and Preliminary Performance Criteria. G. A. Sleater. NBS Tech. Note, v. 941, 1977, pp. 1-74.*

To evaluate preservatives for stone in historic buildings and monuments a laboratory research program of accelerated simulated stone decay was used to obtain data on over 50 materials used as stone preservatives and to suggest criteria for their selection. Tests to simulate stone decay were of 2 types: (1) exposure to combined weathering factors using a special test chamber for accelerated decay, in which chemical attack, salt and water action, and thermal effects were simulated in one operation; and (2) exposure to single causes of stone decay using H₂SO₃ fog, NaCl fog, water condensation/evaporation cycling, Na₂SO₄ penetration and crystallization, and UV irradiation. Methods for measuring the effects of the exposures are given together with the test data; these have been used to set limits of acceptable performance in preliminary performance criteria for the selection of stone preservatives. The behavior of each stone preservative tested in meeting these criteria is given.

15. The Acropolis in Danger. A. M. Bow. UNESCO Courier, v. 30, Feb. 1977, pp. 4-6.

After resisting the onslaughts of weather and human assailants for 2,400 years, this magnificent monument, on which Ictinos and Phidias left the imprint of their genius, is threatened with destruction as a result of the damage which industrial civilization has increasingly inflicted on it for a number of years.

16. The Crystallization and Efflorescence of Salts and Their Deteriorating Effect on the Building Material. J. Sramek. Technicko-ekonomicke Informace PSO, Nos. 5-6, 1977, pp. 27-35 (Czech).

The physical and chemical interaction of water from ground seepage, precipitation, or condensation on the walls is the main factor in mobilization of soluble salts. The pressures produced during crystallization are then comparable with those during freezing of water within the pores. Because crystallization cycles (and hydration-dehydration cycles) are much more probable in comparison with freezing-thawing cycles in the Middle European climate, the salts seem to be the principal cause of decay of monuments.

17. The Decay of Building Stones: A Literature Review. E. M. Winkler. Bulletin, Association for Preservation Technology, v. 9, No. 4, 1977, pp. 53-61.

The decay of building and decorative stone has caused concern for centuries. Frost, solar radiation and the presence of salts are instrumental in the mechanical destruction of rock and stone. The processes of chemical weathering consist of the relatively simple dissolution of carbonates and the very complex solubilization of silicate minerals. The penetration of hydrogen ions into the crystal lattice appears to be the most destructive factor in the weathering of the feldspars. Microbial life often invades masonry and is a significant deteriorating factor.

18. The Effect of Air Pollution on Buildings. J. Riederer. Handbuch des Umweltschutzes, 1977, pp. T2.63.1-4 (German).

Recent investigations proved that increasing levels of sulfates in the walls of historic buildings are due to mortars used in the 19th and early 20th century, when cements with high amounts of sulfates were used. On the the other hand, dark incrustations, which absorb SO_2 and transform it to sulfuric acid because of high amounts of catalytic agents, may be highly corrosive for stone.

19. The Maintenance of Ancient Monuments in Greece. J. Riederer. Berl. Beitr. Archaeom., v. 2, 1977, pp. 146-159 (German).

Ancient monuments in Greece are threatened by weathering. Soft limestones decay rapidly; marbles are more resistant. Various forces of natural weathering cause the decomposition of building stones, in concert with ground moisture and efflorescence of salts. According to the author, air pollution has no influence on the decay of stone even in Athens. Biological attack may be very strong; lichen attack on marble can frequently be observed. Visitors cause deterioration if they are allowed to walk on ancient walls. Treatments are discussed.

20. Two Methods for Characterizing Weathering Processes of Inorganic Building Materials. K. Niesel and P. Schimmelwitz. Materialpruefung, v. 19, No. 8, August 1977, pp. 310-314 (German).**

This paper deals with two methods contributing to a better understanding of the weathering processes of inorganic building materials, especially under the effect of sulfurous air pollutants. Both have been developed at the German Federal Republic's Institute of Testing Materials. The weathering conditions at the building are simulated by a device in which the specimens are subjected to a continuous air flow with a given SO_2 concentration (15 ppm) and at alternative humidities for a longer time. As for most of these methods, the time factor has to be replaced by intensifying the other influences. In order to characterize layers of different mechanical strength running parallel with the material surface, as found in the outer zone of weathered building stones, their abrasion behavior may be used. This is made possible by an apparatus in which loose abrasives are conducted over the even surface of the specimen by a polished disk. The loss in thickness per stress cycle serves as a measure for the abrasion resistance of the material. The method is especially suitable for testing medium hard to soft samples.

21. Weathering and Preservation of Ancient Building Material. B. Lal. *Studies in Museology*, v. XII, 1976-77, pp. 28-43.

In this paper, the author has enumerated the different types of stones used in the construction of monuments in the different parts of India and has reviewed in general terms the effect on stone of various factors like atmospheric impurities, water, plants and animals and human vandalism and the various methods of treatment for conserving such monuments and objects. Finally he details the different synthetic preservatives for stone and their properties and application.

1976

1. A Recent Survey on Air Pollution in Venice in Relation to the Deterioration of Marble and Stone. V. Fassina. *Lithoclastia*, v. 2, No. 2, 1976, pp. 33-43.*

Atmospheric pollution by HCl and S compounds, for example, SO_2 , sulfates, and H_2SO_4 , deteriorated exposed marble and other stones. Scanning electron microscopy of internal fracture surfaces in the decayed layers showed abundant NaCl and CaSO_4 crystals. The mechanism of deterioration is discussed.

2. Accelerated Weathering Test for the Study of Stone Treatments. V. Furlan and F. Girardet. *The Conservation of Stone, Proc. of the Int. Symp., Bologna (June 19-21, 1975)*, edited by R. Rossi-Manaresi, 1976, pp. 713-729 (French).

Test samples are placed to form a wall between two chambers whose atmosphere may be regulated to simulate external and internal air conditions. Humidity and temperature cycles show that a surface treatment may increase frost damage.

3. Acid Precipitation. G. E. Likens. Chem. Eng. News, v. 54, No. 48, 1976, pp. 29-31, 35-37, 42-44. (Fe76-1)
4. Air Pollution: A Select Bibliography. G. Marsh. ICCM Bulletin, v. 2, No. 4, December 1976, pp. 21-24.

An annotated bibliography of articles, books, and indexes on the subject of air pollution with particular reference to the conservation of cultural materials.

5. Artificial Aging System of Stones Using Ammonium Bisulfate Solutions. M. Marabelli, P. Rossi-Doria, and M. Tabasso-Laurenzi. The Conservation of Stone, Proc. Int. Symp., Bologna (June 19-21, 1975), edited by R. Rossi-Manaresi, 1976, pp. 763-776 (French).

Solutions of NH_4HSO_4 (2 to 5 percent) were used as artificial aging systems for marble to simulate the attack on stone monuments and buildings by a polluted atmosphere. The NH_4HSO_4 system caused a loss in weight, absorption of water, and increased porosity in the marble samples. This artificial aging system was compared with other types of aging systems, such as freezing-thawing, and crystallization with Na_2SO_4 .

6. Atmospheric Attack (Marbles) and Measures to Take. T. Skoulikidis, D. Charalambous, P. Papakonstantinou. Proc. 2nd Int. Symp. on the Deterioration of Building Stones, Athens, 1976, pp. 327-345 (French).

The authors studied the effects of atmospheric attack on the surfaces of the Acropolis sculptures. Three types of attack were identified: sulfation, corrosion, and cracking with associated danger of detachment. Photographs of the sculptures indicate the areas of each form of deterioration. Gypsum layers 0 - 5mm thick are found in areas washed by rain. Ruptures in the sulfate crust accelerates the attack of marble beneath through zones of preferential topochemical action. Black areas where colloidal deposits of soot are associated with sulfates crusts in areas not washed by rain, and where the polish has worn away.

7. Behavior of Some Soluble Salts in Stone Deterioration. A. Arnold. Proc. 2nd Int. Symp. on the Deterioration of Building Stones, Athens, 1976, pp. 27-35.

Analytical experiments were conducted for 2 years at a number of buildings in restoration, to study, the composition, behavior and origin and observations (on the most common soluble salts which are the chlorides, nitrates, carbonates, sulfates and their behavior on building materials) are presented and discussed.

8. Brick, Adobe, Stone, and Architectural Ceramics: Deterioration Processes and Conservation Practices. G. Torracca. Preprint from Preservation and

Conservation: Principles and Practices, edited by Sharon Timmoris, The Preservation Press, 1976, pp. 143-165.

The following subjects are discussed: deterioration processes of hard masonry materials (porosity and water; chemical processes, access of water (by rain, or directly through air); wind, mechanical stresses and thermal cycles; biological action; study and diagnosis of deterioration processes); conservation practices of hard masonry materials: (conservation of stone, plastic, architectural ceramics); and deterioration processes and conservation of soft masonry materials such as clay.

9. Chemoautotrophic Microorganisms in Semi-Insulated Environment.
L. Barcellona-Vero, C. Bettini, and M. Monte-Sila. Proc. 2nd Int. Symp. on the Deterioration of Building Stones, Athens, 1976, pp. 61-65.

Researches were carried out at the two Estrucan tombs to:

(1) ascertain the spreading of sulfur and nitrogen cycle bacteria on stone materials of this specific environment in relation to those of open air environments; (2) to establish the relationship between heterophobic and autotrophic microflora; (3) to correlate the kind of biological colonization to the peculiarities of the tombs (structure, time of opening, etc.).

10. Climatic Chamber for Laboratory Experiments on the System Sulfur Dioxide--Wet Marble--Airborne Particles. S. Fuzzi and O. Vittori. The Conservation of Stone, Proc. Int. Symp., Bologna (June 19-21, 1975), edited by R. Rossi-Manaresi, 1976, pp. 651-661.

A climatic chamber was constructed for laboratory evaluation of the chemical and physical parameters of atmospheric SO₂-wet marble--airborne particles system. In the chamber, both fixed climatic conditions (temperature, humidity, etc.) and realistic pollution (SO₂ and particles) levels can be easily obtained. Moreover, thermodynamic runs, reproducing those assumed to occur in nature, can allow long-term damages to marble samples to be visualized in a short series of experiments. The microscale pattern of marble deterioration can be observed in detail by using ³⁵SO₂.

11. Conservation of Monuments. 2nd Session of the 24th National Congress of the Assoc. Termotecnica Italiana, Florence (September 25-27, 1974). Antonio Barbieri, Viale Premuda 2, Milano, 1976, 252 pp. (Italian). (OM76-4)

12. Conservation of Natural Stone. L. Arnold, D. B. Honeyborne, and C. A. Price. Chemistry and Industry (London), v. 8, April 17, 1976, pp. 345-347.

To preserve stone, the major destructive agent which should be excluded is water. Limestones react with sulfur dioxide dissolved in rain water to form calcium sulphate which decays the stone by repeated

crystallization. The crystallization of ice is another decay mechanism. The more promising materials being used to impregnate stone are alkoxy silanes, low molecular weight epoxy resins and waxes. Those treatments serve to restore or increase the tensile strength of the stone and thus making them more resistant to crystallization forces or to make the salts inaccessible to water.

13. Contribution to the Study of the Alteration of Buildings of the Acropolis. P. De Henau and M. Dupas. Proc. 2nd Int. Symp. on the Deterioration of Building Stones, Athens, 1976, pp. 319-325 (French).

Samples from Athenian marble monuments, namely, the Parthenon, Agora, Poseidon temple, and Delphi were examined to determine to causes of deterioration and alteration for conservation purposes. The samples contained soluble salts, as SO_4^{2-} , NO_3^- , NO_2^- , Cl^- , Ca, Na, and Mg, the levels of Cl^- and NO_3^- being <0.5 percent in nearly all samples. Sample surfaces also exhibited mosses and dark brown and greenish brown algae. The acidity of rainwater, enhanced by industrial air pollutants, appeared to have an effect on marble corrosion. Photomicrographs of the samples are presented.

14. Control of Moss, Lichen and Algae on Stone. B. A. Richardson. The Conservation of Stone, Proc. of the Intern. Symp., Bologna (June 19-21, 1975), edited by R. Rossi-Manaresi, 1976, pp. 225-231.

The growth of moss, algae and lichen depends on the nature of stone, the climatic conditions and the degree of pollution. Polluted atmospheres prevent the growth, but the biological activity is still present. On the basis of some tests, two formulations are recommended for the prevention of growth of moss, algae and lichen.

15. Decay of Pietra Serena and Pietraforte, Florentine Building Stones. V. Relationships Between Mineralogical-Petrographic and Chemical Analyses. A. Bencini, P. G. Malesani, and S. A. Vannucci. Conservazione dei Monumenti, 1976, pp. 121-124 (Italian).

The deterioration processes of two sandstones widely used in Florence have been studied by mineralogical-petrographical techniques and X-ray diffraction. Carbonates are dissolved and precipitated in the outer zone of the stone. Sulfates may be the products of the metabolic activity of sulfur-bacteria.

16. Effects of Air Pollution on Building Materials in Monuments. G. Torraca. Conservazione dei Monumenti, 1976, pp. 7-13 (Italian).

Air pollution causes a modification of deterioration processes resulting in an increased rate of attack or in deterioration of materials which are weather-resistant in non-polluted environments. Present conservation processes are rather efficient but their results are ephemeral if treated materials remain exposed to an aggressive

environment. The safety of cultural property exposed to environmental deterioration depends upon the operation of protection systems and maintenance services.

17. Effects of Atmospheric Pollutants on the Composition of Black Crusts Deposited on Venetian Marbles and Stones. V. Fassina, L. Lazzarini, and G. Priscondin. Proc. 2nd Int. Symp. on the Deterioration of Building Stones, Athens, 1976, pp. 201-211.

In this paper, the concentration of trace elements present in air and in black crusts have been taken into consideration in order to identify their role in the corrosion processes. Moreover, the authors looked to correlate the analyses of atmospheric pollutants, total soluble sulfate and chlorides, with those of black crusts deposited on the surfaces of monuments. Attention was focused on secondary pollutants because the authors believed that the aerosol particles play an important role.

18. Effects of Gaseous Pollutants on Materials: A Chamber Study. F. H. Haynie, J. W. Spence, and J. B. Upham. NTIS Report PB-251580, 1976, 98 pp. (Fe76-5)

19. Effects of Power Plant Emissions on Materials. J. E. Yocom and N. Grappone. Research Corporation of New England, Wethersfield, Connecticut, NTIS Report PB-257539, July 1976, 85 pp. (Fe76-6)

20. Effects of Pollutants on the Deterioration of Objects of Art in Stone--State of the Researches at the Secteur Sauvegarde' at Bordeaux. J. G. Faugere, F. Inffau, B. Salinieres, and J. Sufori. Proc. 2nd Int. Symp. on the Deterioration of Building Stones, Athens, 1976, pp. 111-115 (French).

The paper presents the results obtained from a study which has five main objectives: (1) study of the facades of stones; (2) study of the geology and hydro-geology of the underground; (3) study of the atmospheric pollution from 1969-1975 by SO_x , NO_x , particulates and pH; (4) study of the rocks, the formation of black deposits, and procedures of cleaning, and (5) study in the laboratory--special researches (efforts of the deposits and the migrations of pollutants).

21. Frequency, Forms, and Causes of Deterioration of Greek Marbles and Stones in Venice. L. Lazzarini and R. Begolli. Proc. 2nd Int. Symp. on the Deterioration of Building Stones, Athens, 1976, pp. 249-255.

The first part of this paper cites the different types of marbles and stones in Venice. The second part describes the forms and causes of the deterioration, and the degree of resistance of each kind of marble and stone.

22. Fundamentals of Atmospheric Corrosion. G. Oelsner and W. Hoepfner. *Werkst. Korros.*, v. 27, No. 5, 1976, p. 354. (OM76-8)
23. Honeycomb weathering--Conditions for Onset and Evolution. J. P. Pauly. *The Conservation of Stone*, Proc. of the Int. Symp., Bologna (June 19-21, 1975), edited by R. Rossi-Manaresi, 1976, pp. 55-80 (French).

Maladie alveolaire is a type of stone deterioration characterized by localized powdering and is connected to two principal factors: hygroscopic salts and hygrometric variations. Areas of facade associated with higher wind turbulence are also areas with greater honeycomb weathering. In laboratory experiments, the form of weathering is dependent upon hygrometric conditions and provide the basis for explaining observed differences in weathering as a function of exposure to rain.

24. Influence of Sulfur Bacteria on the Deterioration of the Stones of Some Historical Buildings in France. P. Tiano and R. Bianchi. *Conservazione dei Monumenti*, 1976, pp. 133-135 (Italian).

The possibility of a connection between the presence of sulfur bacteria and of gypsum on decayed stones is studied. A statistical analysis of the results obtained seems to support such a possibility. A technique is suggested to confirm these results.

25. Inquiry and Study on the Cologne Cathedral and Its Building Material. S. Luckat. *Schrift. Lik*, v. 37, 1976, pp. 112-122 (German).*

During six centuries, a variety of natural rock types have been used in the construction and maintenance of the cathedral, and pollutants in the surrounding atmosphere have caused varying degrees of damage. In 1972-5 the extent and nature of such damage was evaluated systematically at various locations and at elevations >100 meters. Protective measures for the cathedral against the pollutants (SO_2 , F^- , and Cl^-) are suggested.

26. Interaction of Sulfur Dioxide With Lime Plasters. D. Hoffmann, P. Schimmelwitz, and H. Rooss. *Proc. 2nd Int. Symp. on the Deterioration of Building Stones*, Athens, 1976, pp. 37-42.

Plasters are artificially weathered at a 15 ppm concentration of SO_2 but at a concentration of CO_2 similar to the one in nature and at a constant temperature of 20°C and changing relative humidities (from 50 to 100 percent). Gypsum and calcium are identified as weathering products of lime plasters. For other varieties of plasters other weathering products are correspondingly formed. The mechanisms of the actions of gypsum and magnesium sulfite or magnesium sulfate on lime plasters are presented and discussed. The results show that those mechanisms are very complex. Furthermore, the artificial weathering does not give comparable results with those of natural weathering.

Therefore, more laboratory tests must be carried out and the observation of naturally weathered plasters has to be elaborated.

27. Investigations on the Decay of Candoglia Marble Used in the Milan Duomo. G. Alessandrini, R. Peruzzi, and L. De Capitani. The Conservation of Stone, Proc. of the Intern. Symp., Bologna (June 19-21, 1975), edited by R. Rossi-Manaresi, 1976, pp. 137-167.

Marble samples taken from different parts of the Duomo have been first examined from the mineralogical-petrological point of view. Their structural and physical characteristics were determined. To complete the study, an investigation was conducted of the historical environmental trends from the mid 1800's to 1973. The final result shows that the degradation of Candoglia marble undergoes both physical and chemical decay which depends mainly on its structural characteristics and secondarily on its physical properties.

28. Isolation of Various Sulfur-Oxidizing Bacteria From Stone Monuments. L. Barcellona-Vero and M. Monte-Sila. The Conservation of Stone, Proc. of the Intern. Symp., Bologna (June 19-21, 1975), edited by R. Rossi-Manaresi, 1976, pp. 233-244.

Sulfur-oxidizing bacteria were isolated in pure cultures from marble, travertine and tufa monuments located in urban and rural environments. Differences in the behavior of various strains of bacteria are shown.

29. Laboratory Measurement of Sulfur Dioxide Deposition Velocities on Selected Building Materials and Soils. H. S. Judeikis and T. B. Stewart. Atmos. Environ., v. 10, No. 9, 1976, pp. 769-776.*

Sulfur dioxide deposition velocities on cements, stuccos, soils, and asphalt were measured in the laboratory using a cylindrical flow reactor. The data were analyzed using models that specifically account for diffusive transport in the system. The values range from 0.04 cm/sec for asphalt to 2.5 cm/sec for cement and were independent of SO₂ and oxygen concentrations, relative humidity, and total pressure. Overall capacities increased significantly at moderate relative humidities yielding values of 0.4 to 2.8 g SO₂/m² of solid in moist systems. The reactivity of a solid subjected to prolonged SO₂ exposures could be restored by washing the surface with distilled water or exposing the spent solid to NH₃.

30. Microprobe Investigations on Incrusted as Well as Cleaned Marble Specimens. E. Hoke. Proc. 2nd. Int. Symp. on the Deterioration of Building Stones, Athens, 1976, pp. 119-126.

Microprobe analysis is used to study crusts on marble samples to determine appropriate cleaning and restoration processes. Untreated samples and samples impregnated with silicone esters were exposed to

SO₂ at a flow rate of 3m/sec for one week in wet and dry conditions. The mechanisms of corrosion and crust formation are described.

31. Natural Dust and Acid Rain. E. M. Winkler. Water and Soil Pollution, v. 6, 1976, pp. 295-302.

Atmospheric dust originates from three sources: terrestrial airborne matter, volcanic, and cosmic. Terrestrial natural dust makes up the main bulk reflecting the soil composition up to 150 miles away. Soil erosion from flood plains, plowed fields and construction sites is the main source. Quartz, feldspar, the carbonates in the atmosphere interact with rainwater converting the carbonates to benign gypsum (CaSO₄·2H₂O). Naturally leached soils produce less calcite than unweathered sediments on flood plains and construction sites, and in granitic and crystalline rocks less than in limestone areas.

Heavy industrialization associated with high emission of CO₂ and SO₂ on the one hand, and excess production of dust on the other, appears to counteract man's interference with natural ecosystems in the opposite direction.

32. Outdoor Weathering: Its Objectives and Limits. F. Rosendahl. Proc. 13th FATIPEC Congress, Cannes, 1976, pp. 563-567 (German). (OM76-13).
33. Physical and Economic Damage Functions for Air Pollutants by Receptors. B. Liu and E. S. Yu. Report No. EPA-600/5-76-011, U.S. Environmental Protection Agency, September 1976, 172 pp. (Fe76-13)
34. Present State of the Research Carried Out in France on Hydrophobic Materials. J. Taralon and G. Oriol. The Conservation of Stone, Proc. of the Intern. Symp., Bologna (June 19-21, 1975), edited by R. Rossi-Manaresi, 1976, pp. 455-476 (French).

The study of ten hydrophobic products tested on two types of stone, sandstone and limestone, is reported. Test methods include: depth of penetration, artificial weathering cycles (ultraviolet and acid atmosphere), freeze-thaw cycles, air permeability, evaporation, natural aging, and crystallization of sulfates.

35. Protection by Cleaning and Conservation. J. Riederer. Das Gebäudereiniger-Handwerk, No. 2, 1976, pp. 14-15 (German). (OM76-18)
36. Reaction of Sulfur Dioxide With Limestone and the Grain Model. M. Hartman and R. W. Coughlin. Amer. Inst. Chem. Engr. J., v. 22, No. 3, 1976, pp. 490-498.*

Experimental measurements of the reaction of SO₂ and oxygen with limestones have demonstrated substantial influence of the geological

origin of the stone, its porosity and particle size, gaseous concentration of SO_2 and temperature on the course of reaction, and the conversion (that is, the degree of utilization of the limestone content of the particles as a solvent for SO_2). A mathematical model including intraparticle transport and chemical reaction within the particles (grain theory) was developed to simulate this SO_2 sorption reaction.

37. Relations Between Corrosion of Sandstones and Uptake Rates of Air Pollutants at the Cologne Cathedral. Y. Efes and S. Luckat. Proc. 2nd. Int. Symp. on the Deterioration of Building Stones, Athens, 1976, pp. 193-200.*

A correlation exists between the high uptake rates of SO_2 and the SO_4^{2-} content in the corrosion layers of the stones. A considerable increase in the SO_2 content in the corrosion layers from the interior to the exterior point was observed at a significant participation of H_2SO_4 for the formation of corrosion products. Mean values of the uptake of Cl, SO_2 , and F are given. Non-siliceous cement, that is, dolomite and calcite, influenced the corrosion.

38. Replacement of Steel Connectors by Titanium Alloys. S. Angelides. Chapter in The Acropolis - Hellenic Republic, Ministry of Culture and Science, Athens, Greece, 1976, pp. 95-96. (OM76-19)
39. Restoration of Ancient Deteriorated Marble Art Objects: Reversal of Sulfation-Utilization of Calcium Sulfate Dihydrate and Transformation of Calcium Carbonate. T. Skoulikidis, P. Papakonstantinou, and D. Charalambous. Proc. 2nd. Int. Symp. on the Deterioration of Building Stones, Athens, 1976, pp. 171-178 (French).

The reversal of the sulfation of surfaces of ancient marble art objects on which gypsum formed was described. This reversal utilizes the reaction $\text{CaSO}_4 \cdot 2\text{H}_2\text{O} + \text{CO}_2 \rightarrow \text{CaCO}_3 + \text{SO}_3 + \text{H}_2\text{O}$ using a CO_2 pressure of 1 atm and a temperature of 25°C . Differential thermal analysis is used to measure the amount of CaCO_3 formed. Applications of the method on Acropolis statues and monuments are discussed.

40. Rock Alteration in a Natural Environment in Understanding Degradation of Monuments. R. Pellizzer and G. Sabatini. The Conservation of Stone, Proc. of the Intern. Symp., Bologna (June 19-21, 1975), edited by R. Rossi-Manaresi, 1976, pp. 3-22.

Weathering processes of silicate rocks are outlined in some detail. The author points out the weakest point in our knowledge concerns not the mechanism but the rate of mineral alteration.

41. Seasonal Conditions Influence Sulfur Bacteria Development on Monuments Exposed to the Open Air. L. Barcellona-Vero and M. Monte-Sila. Conservazione Dei Monumenti, 1976, pp. 12-128 (Italian).

By microbiological analyses on samples drawn from various monuments in Rome, a presence of oxidative sulfur bacteria as thiobacillus and reducing sulfur bacteria as desulfur has been noticed.

42. Soluble Salts and Stone Weathering. A. Arnold. The Conservation of Stone. Proc. of the Intern. Symp., Bologna (June 19-21, 1975), edited by R. Rossi-Manaresi, 1976, pp. 133-135.

The observations on the efflorescences of soluble salts from 50 samples summerized as follows:

1. The presence and nature of soluble salts are independent from the kind of stone. They are found on different rock types as well as on mortars and plasters.
2. The efflorescences appear preferentially in winter time and they tend to disappear in summer time.
3. The efflorescences are concentrated on certain parts of the buildings such as: the upper zone of rising water, the zones below terraces, cornices and roofs which are not tight, the zones beside defective gutters and zones adjacent to tight basal stones.
4. The soluble salts migrate with the water in and out of the stone as well as along the surfaces of the stone. Small amounts distributed over a large surface may be concentrated by rain water on small areas where they give rise to accelerated deterioration. It can also be observed that the salts migrate during and after each period of rain.

43. Stones and Marbles in Venice and their Decay. L. Lazzarini. The Conservation of Stone, Proc. of the Intern. Symp., Bologna (June 19-21, 1975), edited by R. Rossi-Manaresi, 1976, pp. 169-187.

The paper discusses a recording program, identifying the varieties of stone used in Venetian monuments, both exterior and interior and the dates of their erection. Tabulations of deterioration by date, locations, and stone type are presented.

44. Stone Deterioration at the Cologne Cathedral Due to Air Pollution. S. Luckat. The Conservation of Stone, Proc. of the Intern. Symp., Bologna (June 19-21, 1975), edited by R. Rossi-Manaresi, 1976, pp. 37-43.

The immission rate measuring apparatus (IRMA) has been used to determine the amount of SO₂, Cl and F absorbed by the stone of the Cologne Cathedral. The monitoring equipment and locations are described. First year data, compared with iron corrosion, are reported.

45. Structural Analysis of Monuments. S. Angelides. Chapter in the Acropolis, Hellenic Republic, Ministry of Culture and Science, Athens Greece, 1976, pp. 19-22. (Fe76-16)

46. Surface Reactivity of Marble and Stone: Quarry and Altered Samples. B. Badan, G. Bacelle, and L. Marchesini. The Conservation of Stone, Proc. of the Intern. Symp., Bologna (June 19-21, 1975), edited by R. Rossi-Manaresi, 1976, pp. 89-101.

The reasons why two types of limestones, Carrara marble and Istrian stone, show different behaviour in the presence of oxygenated compounds of sulfur are clarified.

Samples both from the quarry or artificially altered or left in the open air for long periods were exposed to sulfuric acid attack either in solution or in aerosol form; the formation of gypsum was followed with the aid of a scanning electronic microscopy.

The growth of crystals mainly of acicular form in the altered areas was observed, while in the other areas of crystals had a lamellar aspect.

47. Tests on the Effectiveness of a Treatment to Conserve Milan Cathedral. G. Alessandrini and R. Peruzzi. *Lithoclastia*, v. 2, No. 2, 1976, pp. 17-31.

Specimens of Candoglia marble taken from the quarry and the Cathedral were treated with the acrylic resin employed on the Cathedral facade. Structural, chemical and physical analyses were carried out by scanning electron microscope, X-ray spectrometer, X-ray diffractor, and porosimeter. Treated and untreated samples were subjected to artificial weathering to check their behavior. The artificial weathering was obtained through exposure to freeze/thaw cycles ($-10^{\circ}\text{C}/+20^{\circ}\text{C}$) alternated with exposure to a controlled atmosphere of SO_2 (80 ppm) in a dynamic system. The decay was monitored by structural, chemical and physical analyses.

48. The Cologne Cathedral--Stone Deterioration, Atmospheric Pollution and Protective Treatment. S. Luckat. *Nachrichten aus Chemie und Technik*, v. 24, No. 13, 1976, pp. 283-285 (German).

A summary account of the many kinds of stone used in the Cologne Cathedral since 1248 A.D., the effects of atmospheric pollution (principally sulfur dioxide) on these stones, and the conservation measures now being taken.

49. The Corrosive Action of Salts. T. Stambolov. *Lithoclastia*, v. 2, No. 1, 1976, pp. 3-8 (French).

The corrosive mechanisms of salts in a brick wall are reviewed.

50. The Deterioration and Conservation of Porous Building Materials in Monuments: A Review of the Literature. T. Stambolov and J. R. J. Van Asperen de Boer. ICROM, Rome, 2nd editor, 1976, 70 pp.

A critical review of literature on such topics as weathering by moisture and salts, moisture in porous building materials, frost damage, wind

46. Surface Reactivity of Marble and Stone: Quarry and Altered Samples. B. Badan, G. Bacelle, and L. Marchesini. The Conservation of Stone, Proc. of the Intern. Symp., Bologna (June 19-21, 1975), edited by R. Rossi-Manaresi, 1976, pp. 89-101.

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A critical review of literature on such topics as weathering by moisture and salts, moisture in porous building materials, frost damage, wind

erosion, insulation, deterioration by biological agents, fire damage, remedial measures against moisture, cleaning, consolidation and protection is presented.

51. The Flow of a Thin Layer of Warm Air Induces a "Wind-Shield Effect" Which Combats Deterioration, Caused by Air Pollution, of Internal Wall Decoration of Churches. G. Massari and I. Massari. The Conservation of Stone, Proc. of the Intern. Symp., Bologna (June 19-21, 1975), edited by R. Rossi-Manaresi, 1976, pp. 421-428.

Humidity in buildings can be controlled in two ways: insertion of damp-proof-courses in the walls to combat rising humidity, and modification of the climate by heating the air which is in contact with the walls. Experiments show that the relative humidity near the wall may be reduced by about 5 percent by means of a heating wire (50 calories/hour per meter length) embedded in the floor near the wall. Reduction of surface relative humidity should reduce deposition of pollutants and water-related deterioration processes.

52. The Ideal of the Ideal Environment. G. W. Rogers. J. Intern. Institute Conserv. - Canadian Group, v. 2, No. 1, Autumn 1976, pp. 34-39.

Various workers have, in the past, proposed constant levels of temperature, humidity, light and pollution which would constitute such an ideal environment for many types of materials. These levels are examined, the practical problems of creating and maintaining some of them are discussed and an attempt is made to evaluate the feasibility of a constant environment in the light of Canadian construction and climatic restrictions. From this study, control based on maximum and minimum acceptable levels appears feasible and these levels could form a basic set of environmental control guidelines for museums, galleries and archives in Canada.

53. The Importance of Preliminary Research Into Biological Factors Before Restoration of Works of Art. S. B. Curri. Atti Convegno Di Studi Sul Restauro Delle Opere D'Arte a Dieci Anni Dall'Alluvione, v. 1, No. 1, November 2-7, 1976 (Italian).

Biological and biochemical action co-operate to degrade marble, sandstone, carbonate and silicate rocks. Methods of research are described for the diagnosis of stone disease. Complete and correct disinfection must precede all treatment of consolidation, cleaning and restoration to avoid costly and difficult recovery.

54. The Limestone of Touraine and Its Alteration. J. Cautru. The Conservation of Stone, Proc. of the Intern. Symp., Bologna (June 19-21, 1975), edited by R. Rossi-Manaresi, 1976, pp. 103-131 (French).

A comparative petrographic study was made of deteriorated and non-deteriorated stone. In decayed samples two main alterations are

described: surface granular alteration and exfoliation. It seems that frost, crystallization of the calcium sulfate, and dissolution of the carbonates by acid water are not sufficient to explain the decay. Perhaps the dissolution of silica is responsible for the loss of the cohesion of this material.

55. Weathered Stone: Proposals for the Standardization of Surface Sample taking and analysis. F. Guidobaldi and G. Santariga. The Conservation of stone, Proceed. International Symp., Bologna (June 19-21, 1975), edited by, R. Rossi-Manaresi, 1976 pp. 777-789.

The results of analyses carried out on weathered stone by various researchers are often not comparable owing to the different methods of taking samples and analyses.

To standardize these methods, we have designed an instrument for taking samples from monument surfaces to controlled depth and we have studied the repeatability of some methods of analysis applied to the decay compounds that can be found more frequently in stone.

The results obtained are discussed.

56. Weathering Rates of Stone in Urban Atmospheres. E. M. Winkler. The Conservation of Stone, Proc. Int. Symp., Bologna (June 19-21, 1975), edited by R. Rossi-Manaresi, 1976, pp. 27-36.*

The decay rate of stone in urban areas is discussed. Corrosive CO_2 , SO_2 , and other ingredients in the air, temperature, fog, decreased wind speed, soluble salts and other factors accelerate the decay rate. Urban weather conditions and compared to desert climates.

1975

1. A Suggested Model for SO_2 - Wet Marble-Airborne Particles Atmospheric System. O. Vittori and S. Fuzzi. ICOM Committee for Conservation, 4th Triennial Meeting, Venice (October 1975), Int. Council of Museums, Paris No. 5-7, 1975, 3 pp.

A model for computing the SO_4^{2-} formed by catalytic oxidation of SO_2 contained in water condensed upon marble surfaces is presented. It derives from a model, tested both in the laboratory and in the field, which describes SO_2 transformation in haze and fog droplets.

Studies on the SO_2 - NH_3 -liquid water system, both in the laboratory and in natural environments, show that atmospheric particles play an important role in the chemical transformation of atmospheric SO_2 in hazes and fogs.

2. Analysis of $\text{SO}_2/\text{CaCO}_3$ Reaction on the Marble Surfaces of Venice Buildings by Radiochemical and Optical Methods. A. Breccia, S. Fuzzi, and O. Vittori. ICOM Committee for Conservation, 4th Triennial Meeting, Venice (October 1975), Int. Council of Museums, Paris, No. 4-2, 1975, 11 pp.

On the basis of a theoretical model suggested by O. Vittori and his co-workers, the oxidation of SO_2 in CaSO_4 on Venice marble surfaces has been investigated by non-destructive techniques (radiotracers and optical methods). Samples of Venice marble have been subjected in the chamber to cycles of heating and cooling in $^{35}\text{SO}_2$ atmosphere with high relative humidity. Other samples have been taken in wet conditions to compare them to the previous ones. Some sample surfaces were partially covered by Venice air particles and FeCl_2 as SO_2 oxidation catalysers.

This kind of "stone sickness", that is, the SO_2 transformation in stable CaSO_4 , seems mainly to be caused by the pollution particles as well as the effect of atmospheric conditions, that is, heating and cooling of Venice stone and marble surfaces.

3. Belgian Research on the Weathering of Externally Exposed Calcareous Stones. M. Kupper. *Lithoclastia*, v. 1, No. 2, 1975, pp. 9-18.

An account is given of the determination of the rates of erosion of calcareous stones when exposed to various environments. The influence of such factors as orientation, biological growths, height above ground, and the proximity of industrial sites is considered. The minimum average dissolution velocity of "petit granite" exposed in the open in the Liege region is 0.25 mm/century.

4. Environmental Exposure System of Studying Air Pollution Damage to Materials. J. W. Spence, F. D. Stump, F. H. Haynie, and J. B. Upham. NTIS Report PB - 240615, 1975, 46 pp. (Fe75-11)
5. Exfoliation of Stone Sculptures: Review of Researches Carried Out on Italian Monuments With Particular Regard to the Reliefs by Wiligelmo on the Cathedral of Modena. R. Rossi-Manaresi. ICOM Committee for Conservation, 4th Triennial Meeting, Venice (October 1975), Int. Council of Museums, Paris, No. 5-3, 1975, 24 pp.

Experimental researches carried out on sandstones and marble showing decay by exfoliation, demonstrated that the alteration mechanism mainly consists of the dissolving of calcitic cement, or of the edges of the calcite granoblasts, made by acid water, followed by crystallization near the surface of the newly formed salts. The repetition of the process leads to the formation of a hard surface skin with loss of cohesion of the underneath stone; the skin loses its support and exfoliation begins.

Carbon dioxide was sufficient, as an acid agent, in the past, to bring about an advanced decay by exfoliation in bad quality stones such as the sandstones studied. This type of decay was only observed in marbles that at the beginning of the industrial pollution had already endured centuries of natural weathering. Marbles that were new around that time and marble that before that time were placed in a museum still show a compact surface.

The phenomenon of the exfoliation can however also be observed in stones in a good state of preservation. Treatments carried out, perhaps last century, with mixtures based on calcium hydroxide, formed hard

skins on carved surfaces which today, before analysis, were taken for an indication of decay. The skins formed by those treatments contain, in general, 50 to 70 percent gypsum; in cross section they appear clearly superimposed on the stone, still compact and with its surface perfectly outlined. On the contrary, surface skins formed by decay are not sharply divided from the underlying stone, since the stone structure is changing gradually from the inner to the outer zone. Moreover the decay skins were found to contain at the most 25 percent gypsum, in the worst condition.

6. Soiling of Building Materials. N. J. Beloin and F. H. Haynie. J. Air Pollution Control Assoc., v. 25, 1975, pp. 399-403.

Building materials (painted cedar siding, concrete block, brick, limestone, asphalt, shingles, and window glass) were exposed at five sites in Birmingham, Alabama to determine the rate of soiling by different levels of suspended particulates.

7. Stone: Properties and durability in Man's Environment. E. M. Winkler. Springer-Verlag, New York, 1975, 230 pp.

Stone is the primary building material of the earth's crust; in its basic function it has appealed to man's most primitive needs and has stimulated his artistic sense since the dawn of civilization. Obelisks, pyramids and colossal stone sculptures of early cultures reached astonishing perfection both in excellence of workmanship and in technique of stone transport.

Despite its antiquity, stone is regaining great popularity as a building material through a revolution in the art of quarrying and finishing. Unlimited combinations of stone textures and colors offer the architect a wide range of applications. Stone: Properties and Durability in Man's Environment, surveys the scientific principles regarding the important stone properties pertinent to the architect's, the engineer's and the stone producer's needs.

Our attention to lasting stone beauty and proper maintenance has increased in recent years in proportion to the acceleration in visible damage to stone exposed to polluted urban air and waters. Time-lapse pictures underscore this theme: they show, since the beginning of industrialization, near-exponential acceleration of stone decay on a statue in the heavily industrialized Rhein-Kuhr area of northwestern Germany. The study of stone in its manifold interactions with a complex and hostile environment can only be understood if all components are explored, including the nature of weathering agents themselves. The information is as applicable to concrete aggregate stone as to building stones and ornamental stones.

8. Study of Some Gaseous and Particulate Pollutants in the Atmosphere of Venice (1972-1973) and Their Effect on the Deterioration of Istrian Stone. M. A. Bertolaccini, A. C. Monteriolo, V. Fassina, and G. Torraca. ICROM, 1975, 45 pp.

This is the first report of one of the three groups who joined the International Center for the Conservation of Cultural Property to conduct a study on atmospheric pollution in Venice and its effect on the stone of monuments. The present report gives data on gaseous and particulate pollutant concentrations over a period of two years and the mechanism of transport of pollutants on stone. Besides SO₂, the concentration of secondary pollutants such as sulfates, chlorides, and total acidity, were also monitored. The aerosol compositions were also studied.

9. Sulfur Dioxide and Material Damage. D. G. Gillette. J. Air Pollution Control Assn., v. 25, No. 12, December 1975, pp. 1238-1243. (Fe75-17)
10. The Deterioration and Conservation of Porous Building Materials In Monuments. T. Stambolov and J. R. J. van Asperen de Boen. ICOM Committee for Conservation, 4th Triennial Meeting, Venice (October 1975), Int. Council of Museums, Paris, No. 5-8, 1975, 14 pp.

The most relevant literature published since 1969 is briefly reviewed. The evidence for air pollution as a factor in stone decay is discussed.

11. The Effects of Air Pollution on the Building Fabric of the Cologne Cathedral. III. S. Luckat. Kolner Domblatt, v. 40, 1975, pp. 75-108 (German).

Testing of fifteen proprietary stone consolidants is reported, carried out on triplicate samples of the seven types of stone found in the Cologne cathedral: four types of sandstone, trachyte, basalt, and a fossiliferous limestone.

12. Types of Weathering of the Stone at the Cathedral in Cologne. A. Wolff. Arbeitsblätter für Restauratoren, No. 1, Group 6, 1975, pp. 52-63 (German).

The architect of the cathedral in Cologne discusses weathering of the various stones that were used for a 700 year period. Only basaltic lava was found to be absolutely stable. The content of hydrochloric acid, sulfur dioxide and hydrofluoric acid in the air is primarily responsible for the destruction, as was determined by exact measurements. Deteriorated parts of the cathedral are replaced by new stones; weak areas are hardened with a silicic acid ester.

1974

1. Artificial Weathering--Is It a Useful Method? W. Papenroth. Defazet--Deutsche Farben-Z, v. 28, No. 6, 1974, pp. 282-284.

The actual state of the art in artificial weathering and the use of different weathering and radiation devices are discussed on the basis of recent results. It is demonstrated that well defined weathering conditions should only be applied to different samples and model substances. Care has to be taken in testing numerous parameters simultaneously.

2. Atmospheric Pollution in the Historic Center of Venice. V. Fassina. *Inquinamento*, v. 16, No. 1, 1974, pp. 21-27 (Italian).*

Sulfur dioxide and hydrochloric acid, suspected to be directly or indirectly responsible for the rapid deterioration of stone in monuments and objects of art, were measured in Venice; 24-hour samples of air were collected almost daily between June, 1972 and May, 1973. The average monthly concentration of SO_2 was 0.037 mg/m^3 in June to 0.258 mg/m^3 in November. Higher levels were consistently found in the winter months. Hydrochloric acid concentrations were 0.019 to 0.050 mg/m^3 , with no seasonal changes. The environmental data support the hypothesis that SO_2 and HCl are involved in the destruction of stone monuments.

3. Current State of Knowledge of Stone Alterations. Causes and Methods of Treatment. G. Torraca. *Mater. Constr. (Paris)*, v. 7, No. 42, 1974, pp. 375-386 (French).

Stone deterioration is reviewed.

4. Decay and Its Prevention in Natural Stone. K. L. Gauri. *Trans. Kentucky. Acad. Sci.*, v. 35, No. 1-2, 1974, pp. 29-36.

Two basic types of weathering were studied. Highly compact rocks such as marble and granite develop a zone of weathering which is quite distinct relative to the texture of the parent rock, and is characterized by reduced specific gravity and augmented capillarity. In less compact rocks such as limestone and sandstone, the pore space in the zone of weathering becomes plugged due to recrystallization of salts obtained by the solution of the parent rock. Two approaches for the preservation of stone are: (1) changing the chemistry of the stone so that the resulting substance is more resistant to atmospheric attack; and (2) providing a protective coating and a cement between dislodged grains by means of impregnation with synthetic organic materials. Water-repellant materials successfully protect the stone from chemical attack and also from mechanical stresses. Protective treatments were determined and tested by laboratory techniques. Proper selection and application of preservatives will prolong the life of architectural and sculptural materials.

5. Decay of Pietra Serena and Pietraforte, Florentine Building Stones: Petrographic Observations. P. Malesani and S. A. Vannucci. *Studies in Conservation*, v. 19, No. 1, 1974, pp. 36-50.

Pietra Serena and Pietraforte, the two stones most frequently used in Florentine architecture, have been considered in this study. Through mineralogical-petrographical study and by determining the physical properties of these materials it has been possible to show clearly that the principal factors of their decay are seepage of water and changes of temperature. The simultaneous appearance of these two factors seems to induce the decay with different characteristics in the two stones. Gypsum, thought by some authors to be one of the main factors in the decay of stones, has been detected in materials already deteriorated; it is a product of decay apparently brought on by natura may take part in a process which accelerates the decay.

6. Decay of Stone Without Smog. J. Riederer. *Umwelt*, No. 1, 1974, pp. 42-43 (German).

This article is a reply to the opinion that the decay of stone on the Cathedral of Cologne is due to air pollution. From the history of conservation of this building it is obvious that natural weathering, primarily frost action, is responsible for the decay. There are numerous documents from the Middle Ages to the 18th century about extensive repairs on the facade. The cathedral was in such bad condition in 1800, that it was proposed it be pulled down. (Only the argument that the Cathedral of Cologne is a national monument prevented these plans.) Schinkel, a famous German architect, had to investigate the condition of the stonework, and in a detailed report in 1816, he describes all phenomena of natural weathering. In the middle of the 19th century, the work on the cathedral was continued; large parts of the completely weathered facades had to be broken down. If there is rapid decay now, this is due to the inferior stones used in the 19th and 20th century, to the high amount of sulfates (now attributed to air pollution) which was actually caused by the extensive use of concrete in the walls, and finally by the questionable restoration techniques of the architects responsible, who used stones which are resistant to air pollution but not to natural weathering.

7. Design of a Laboratory Experiment to Identify the Effects of Environmental Pollutants on Materials. J. W. Spence and F. H. Haynie. *Corrosion in Natural Environments*, American Society for Testing and Materials, ASTM STP 558, 1974, pp. 279-291. (Fe74-10)
8. Effect of Air Pollution on Materials and Technical Equipment. D. Knotkova, K. Barton, and B. Dolezel. *Ochr. Ovzdust.*, v. 6, No. 6, June 1974, pp. 75-83 (Czech). (Fe74-12)
9. Efficiency of Epoxy Resins as Stone Preservatives. K. L. Gauri. *Studies in Conservation*, v. 19, No. 2, 1974, pp. 100-101.

A stone-preserving epoxy resin, Epi-Rez (manufactured by the Celanese Coating Co.), was evaluated on calcite in a SO₂-enriched atmosphere for its preservability. Epi-Rez 504, a mixture of Epi-Rez 510 (bisphenol-A diglycidal ether) plus 503 (aliphatic diglycidal ether), was more reactive than 510 alone; thus, the reactivity due to the aliphatic group (Epi-Rez 502) was tested. Epi-Rez 502 treated stone was five-fold more reactive in a SO₂ atmosphere than an untreated one.

10. Speed of Erosion of Paleozoic Calcareous Rocks in Belgium Exposed to Environmental Air and Water. M. Kupper and A. Pissart. *Abhandlungen der Akademie der Wissenschaften in Gottingen-Mathematisch-Physikalische*, v. III, No. 29, 1974, pp. 39-50 (French).

Measurements of the weathering rate have been made on tombstone of "petit granite" (Lower Carboniferous limestone), by determining the amount of relief developed on the polished or sawn surface after exposure to atmospheric processes for a period of between 5 and 120 years. The results give a mean value of erosion of 0.25 mm a century for all stone studied. Erosion due to the flow of water over limestone blocks forming the top of the Ourthe and Soor dams has also been measured.

11. The Economic Damages of Air Pollution. T. E. Waddell. NTIS Report PB-235701, 1974, 156 pp. (Fe74-21)

12. The pH of Rain and the Destruction of Alkaline Stone. G. Thompson and R. White. *Studies in Conservation*, v. 19, 1974, pp. 190-191.

Experiments done on powdered chalk and marble chips showed that a small change in the pH of a solution has a great effect on the corrosion rate of the stones. The results obtained were: the ratio of the corrosion rate for solution at pH 5.25 and pH 4 was about 1/75 and the ratio for pH 5.25 and pH 4.5 was about 1/40 for chalk. Marble chips took a great deal longer to dissolve, but the ratio for pH 3.1 and pH 4.0 appears similar to that for chalk.

13. The use of Weather and Climatological Data in Evaluating the Durability of Building Components and Materials. L. W. Masters and W. C. Wolfe. NTIS Report COM-74-50841/7, August 1974, 102 pp. (Fe74-25)

1973

1. A Radiochemical Method for the Study of the Oxidation of Sulfur Dioxide Absorbed on Limestone. M. Serra and G. Starace. *Problemi di Conservazione*, 1973, pp. 387-393 (Italian).

An experimental method is described to determine the oxidized fraction of sulfur dioxide absorbed by limestone from an atmosphere containing ³⁵S labeled sulfur dioxide.

2. A Review of Natural Stone Preservation. G. A. Sleater. National Bureau of Standards, Washington, D.C, Center for Building Technology Preliminary Report, Report No. NBS IR-74-444, 1973, 41 pp.

With increased interest in stone preservation, it is desirable to know what causes stone to decay, and what materials can be used to preserve stone. This review covers the following topics: causes of stone decay, including faults in the stone, salts, natural weathering factors, air pollution, living organisms, and most importantly, water action; various materials that have been used to preserve stone, including paints, waxes, oils, inorganic chemical surface treatments and impregnants, silicones, silicates, and synthetic organic polymers; methods of evaluating stone preservatives. Field and laboratory procedures for testing stone preservatives, the cleaning of stone, a glossary, and a bibliography are given in appendices.

3. Bibliography of German Literature About the Weathering and Preservation of Natural Stone. J. Riederer. Deutsche Kunst und Denkmalpflege, v. 31, No. 1-2, 1973, pp. 106-118 (German).

About 500 titles of German publications concerning decay of natural stone on monuments and various techniques for the preservation of stone are listed.

4. Distribution of Calcium Oxalates $\text{CaC}_2\text{O}_4 \cdot \text{H}_2\text{O}$ and $\text{CaC}_2\text{O}_4 \cdot 2.25 \text{H}_2\text{O}$ on External Deteriorated Surfaces of Stones in Monuments. V. A. Rossetti and M. Tabasso-Laurenzi. Problemi di Conservazione, 1973, pp. 375-386 (Italian).

Samples from several monuments were analyzed using X-ray diffraction and thin layer chromatography to investigate the origin of oxalates and their possible role in the deterioration of stone. An appendix by L. Barcellona-Vero reports the results of microbiological analysis of the same samples.

5. Effect of Air Pollutants on Stone Weathering. S. Luckat. Staub-Reinhalt Luft, v. 33, No. 7, July 1973, pp. 283-285.**

Investigation of weathering in monuments, measurement of sulfate content, and comparison with SO_2 emissions, show clearly that air pollution is the cause of accelerated deterioration of the stone. Comparison of photographs over 90 years show that the severe effects start with this century, and increase in their attack with each decade. This attack is independent of the length of the previous exposure to the atmosphere. Experiments on Cologne Cathedral with its many varieties of stone show that sulfation is not only superficial, but penetrates deep into all of the stones.

6. Influence of Air Pollution on the Conservation of Limestone Monuments. S. Barcellona, L. Barcellona-Vero, and F. Guidobaldi. Problemi di Conservazione, 1973, pp. 427-437 (Italian).

A report is made on the analysis of the facade of S. Giacomo Degli Incurabili in Roma. The type and distribution of organic components of the weathering crusts were studied in detail. Results show the presence of large quantities of calcium sulfate, and several organic compounds from soot or from the metabolism of micro-organisms were identified.

7. Influence of Thiobacteria on Stone Deterioration Processes. L. Barcellona-Vero, M. Monte-Sila, and A. Silveri. Problemi de Conservazione, 1973, pp. 439-451 (Italian).

Samples of deteriorated stone from three monuments in Aquila (Italy) were analyzed. Both sulfur-oxidizing and sulfur-reducing bacteria were identified and their activity evaluated. The influence of temperature and humidity on the development of Th. Thiooxidans, Th. Thioparus, and D. Desulfuricans was studied. At optimal relative humidity values these micro-organisms were found to be resistant to the maximum ambient temperature.

8. Marble. Stone. M. Tabasso-Laurenzi and G. Torraca. Problemi di Conservazione, 1973, pp. 49-62 (Italian).

Stone structure, composition and mechanical properties, deterioration processes and influence of microclimate are studied. A discussion of stone conservation includes: cleaning, consolidation and protection, and the testing of conservation processes.

9. Reactivity of Treated and Untreated Marble Specimens in an SO₂ Atmosphere. K. L. Gauri and A. C. Sarma. Studies in Conservation, v. 18, No. 1, February 1973, pp. 25-35.

Marble specimens were impregnated with epoxy resins by first soaking the specimens in a solvent and then treating them, in steps, with increasing concentrations of the resin in the resin-solvent mixture. This resulted in impregnation to several centimeters depth into the specimen. Both impregnated and non-impregnated specimens were subjected to 3,000 ppm SO₂ atmospheres in a dynamic system. X-Ray diffraction and fluorescence studies to determine the deterioration quantitatively, revealed that transformation of the outer layer of non-impregnated marble into primarily calcium sulfite stopped after a maximum of 15 mole percent conversion under normal conditions of humidity. While certain impregnated marble specimens showed significant protection from SO₂ attack, other impregnated specimens revealed more reactivity than the controls. A partial explanation of this has been obtained by scanning electron microscopy which showed that the resin films on the surface were perforated. Coatings of certain acrylics provided some additional protection to impregnated specimens.

10. Salt Action on Stone in Urban Buildings. E. M. Winkler. Application of Science in Examination of Works of Art, edited by W. J. Young, Museum of Fine Arts, Boston, 1973, pp. 139-153.

Salts may derive from ground moisture, stone weathering and polluted air, they may travel in stone by diffusion and capillarity. Relation of solute concentration to osmotic pressure at various temperatures is given for MgSO_4 , Na_2SO_4 , MgCl_2 and NaCl . The development of high pressures by efflorescences is discussed, and the hydration pressures of some common salts is tabulated. The process of damage due to moisture, with or without the presence of salts, is extremely complex.

11. Stone Conservation in Bavaria. J. Riederer. Jahrbuch Bayer, Landesamt fur Denkmalpflege, v. 28, 1973, pp. 264-283 (German).

About 200 stone objects, which were treated during the last few years in Bavaria, are listed. The various causes of the decay are explained. Natural weathering is the main destructive force, but the decay which is due to harmful methods of cleaning and consolidating stone is also notable. Although the Bavarian monuments are seriously threatened by stone decay, no dangerous signs of the effect of air pollution could be found. The application of synthetic resins is the dominant method of treatment; waterglass is still in use, but has largely been replaced by the silicate esters. Other methods were applied for only a few objects.

12. Stone Decomposition and Conservation in Westphalia-Lippe. K. Schmidt-Thomsen. 3d Int. Union Air Pollut. Prev. Assoc.-VDI-Komm. Reinhaltung pp. A93-A97 (German).

The discussion covers the effect of air pollution and other environmental factors on the sandstone and limestone monuments and statues in Westphalia as illustrated by some photographs taken at the beginning of the century and recently, and the use of ethyl polysilicate to restore or protect these works of art.

13. Studies of the Effect of Air Pollution on the Construction Materials of the Cologne Cathedral. A. Wolff and S. Luckat. 3rd Int. Union Air Pollut. Prev. Assoc.-VDI-Komm. Reinhaltung Luft Int. Clean Air Congr. Proc., 1973, pp. A90-A91 (German).

The lower of sulfur dioxide levels in the atmosphere as a result of train electrification was followed by even faster deterioration of the cathedral exterior. The uptake by the cathedral of sulfur dioxide, hydrogen chloride, the hydrogen fluoride was about twice as great at a height of 65 m as at 20 m. Uptake of sulfur dioxide was much greater in the winter, indicating sources such as power plants. Hydrogen chloride and hydrogen fluoride uptake rates showed strong fluctuations but no recognizable tendency. About 50 different types of stone were used in the construction. The Cologne atmosphere also contains hydrogen sulfide and nitric oxide. The present and anticipated deterioration of the most important stones used in constructing the cathedral is briefly

described as well as the scheme for monitoring the atmosphere at different locations of the cathedral for composition and corrosion.

14. The Damaging Effects of Air Pollution on Works of Art. J. Riederer. 3rd Int. Union Air Pollut. Prev. Assoc.-VDI-Komm. Reinhaltung Luft Int. Clean Air Congr. Proc., 1973, pp. A86-A89 (German). (Cu73-3)
15. The Relatively Negligible Effect of Air Pollution on Stone Deterioration. J. Riederer. Staub-Reinhaltung der Luft, v. 33, No. 1, 1973, pp. 15-19 (German).

The contribution of air pollution to the decay of stone is unimportant compared with the action of climatic and biological forces. Limestone, which theoretically should be attacked by aggressive rain, is always in good condition. considerable damage occurs on sandstones, but their decay is not due to air pollution for most sandstones do not contain compounds which react with SO_2 , and there are no sulfates as reaction products. The argument that sulfates are removed by the rain is wrong, for sulfates coming from the ground moisture or the action of bacteria are never removed. For most of the great sandstone objects there are accounts of preservative treatments from former centuries, which show that the decay is not a phenomenon of our time. On buildings far away from industrial and urban areas the decay is not less than in polluted areas. The deposits of gypsum on stone are not reaction products due to air pollution, but deposits of solid material, for the same crusts are found on calcium-free sandstones and metals, too. This transformation of the urban dust, which is rich in calcium compounds of the soot. The waste gases of automobiles do not contain compounds which have any influence on stone.

16. The Sandstone of the Basilica of San Michele in Pavia. Studies on Deterioration and Effects of Preservative Treatment. F. Aguzzi, A. Fiumara, A. Peroni, R. Ponci, V. Riganti, R. Rossetti, and F. Soggetti. Atti. Soc. Ital. Sci. Nat., v. 114, No. 4, 1973, pp. 403-464 (Italian).

A petrographic, climatologic and microbiological study was made of deterioration of sandstone in one monument. The combined action of air pollution and meteorological factors were seen as the major cause of decay. Bacteria of the sulfur cycle appeared to be absent. Effects of stone treatment by fluorosilicates and ethyl silicate were studied and compared.

1972

1. Causes of Deterioration of Stones Exposed to the Environment and Methods of Intervention. G. P. Guidetti. Atti Dell'Accademia Delle Scienze Di Ferrara, v. 49, 1971-72, pp. 37-59 (Italian).

A general discussion is given of causes of deterioration of stone and consolidation techniques.

2. Conservation of Stone: Causes of Decay. W. H. Dukes. The Architect's J. Information Library, v. 23, August 1972, pp. 429-432.

The factors which cause stone to decay are discussed. These include atmospheric pollutants (SO_2 , SO_3 , CO_2), soluble salts, frost, thermal stress, algae, fungi, lichens and mosses.

3. Environmental Deterioration and Evaluation for Dimension Stone. M. Sengupta and A. A. de Gast. Canadian Mining and Metallurgical Bulletin, v. 65, 1972, pp. 54-58.

With rapid deterioration in the urban environment caused by air pollution, the possibility of chemical reaction between dimension stone and the industrial waste gases present in the ambient atmosphere remains. The chemical reaction can cause expensive damage to building stone; it is essential that a stone evaluation for use in construction should assess the possibility of this type of decay.

This paper endeavours to develop testing procedures for evaluating stone decay in polluted environments. Such tests can accompany other standard tests used in dimension-stone evaluation.

4. Investigations Concerning the Protection Against Air Pollutants of Objects of Natural Stone. S. Luckat. Staub-Reinhaltung der Luft, v. 32, No. 5, May 1972, pp. 30-33.

Air pollutants play a more or less important role in the corrosion of most diverse materials, and they constitute an important factor in the destruction of objects of certain natural stones.

An acute problem has emerged, and is being dealt with in the framework of investigations undertaken by this author, namely the rapidly increasing deterioration, over the last decades, of art objects, found in the State of North-Westphalia in great numbers, which are subjected to the direct effect of the atmosphere. These objects include, e.g., castles, water-surrounded palaces, sculptures mounted on these or other buildings or standing by themselves and, last but not least, the Dome of Cologne.

An investigation program was therefore set up, in cooperation with the two Monument Authorities of the State of North Westphalia, for the protection of these irreplaceable objects. This paper deals with certain aspects of this program and with already available results.

5. No Destruction of Stone By Air Pollution. J. Riederer. 1st Colloque International sur la Deterioration des Pierres en Oeuvre, 1972, pp. 119-124.

The contribution of air pollution to the decay of building stones is unimportant compared with the effect of climatic and biological forces. This is confirmed by the following arguments: (1) limestone, which

theoretically ought to be attacked by the corrosive components of rain, does not show serious damage in Germany; (2) deepest decay occurs on sandstones and this decay is not due to air pollution because most sandstones do not contain components which could react with pollutants; (3) there is no sulfate formation, except that which is apparently due other influences; (4) the decay of sandstone by natural weathering has been thoroughly investigated since the 19th century and there is no difference between these early observations and our own; (5) objects which show the greatest deterioration today were treated extensively in the past; (6) damage in rural areas is as serious as that noted in urban areas; (7) crusts of gypsum, which are thought to be reaction products of polluted air and stone, occur on intact limestones and bronzes.

6. Properties of Carbonate Rocks Related to Sulfur Dioxide Reactivity.
R. H. Borgwardt and R. D. Harvey. Environ. Sci. Tech., v. 6, No. 4, 1972, pp. 350-360.

Petrographic examination and grain size-distribution measurements were made on 11 specimens representing a broad spectrum of limestones and dolomites. The SO_2 reaction kinetics of calcines prepared from each rock type were determined at 980°C . Stones of various geological types yield calcines of distinctly different physical structures that show correspondingly large differences in both rate of reaction and capacity for SO_2 sorption. Pore size and particle size together determine the extent to which the interiors of individuals particles react. Particles smaller than 0.01 cm with pores larger than $0.1\text{ }\mu\text{m}$ react throughout their internal pore structure at a rate directly proportional to the BET surface. The rate decays exponentially as sulfation proceeds until the pores are filled with reaction product. The ultimate capacity of small particles is determined by the pore volume available for product accumulation, which is generally equivalent to about 50% conversion of the CaO in limestones. Variations in effectiveness of carbonate rocks for flue gas desulfurization are explained by the physical properties of their calcines, which are related to the crystal structure of the original rock. The high reaction rates achieved in the limestone injection process apparently result from the large surface area existing for short periods immediately following the dissociation of CaCO_3 .

7. Protection of Materials Made of Natural Stone From Air Pollution.
S. Luckat. Staub-Reinhaltung der Luft, v. 32, No. 5, 1972, pp. 217-220 (German).

An accelerated test method was used for evaluation of the protection against the corrosive effects of atmospheric pollutants rendered by 5 treatments applied to five types of stones representative of materials from which art objects (sculptures, monuments, etc.) are made. The following protective compositions were tested: Keim-Fixative (a potassium-water glass composition), Sikovin (a hydrophobic agent based on silicone), Tegovakon (a hydrophobic agent-silicate mixture), Krautol 1312 (an acrylic resin), and MOS GR (unknown composition). The protective effect depended on the composition and the type of stone. Only Tegovakon gave satisfactory results in all cases.

8. Studies on the Physical-Chemical Deterioration of Some Monuments in Siena and on Possible Criteria for Protection and Consolidation. L. Falciai, R. Pellizzer, R. Rossi-Manaresi, and G. Sabatini. *Atti Dell'Accademia Delle Scienze Di Ferrara*, v. 49, 1971-72, pp. 83-102 (Italian).

From analyses of marble sculptures variously exposed to the environment or transferred inside in 1858, an hypothesis is formulated on the deterioration process. Wetting-drying cycles determined by rain or condensation and accelerated by air pollution are considered.

9. Use of Silicones in Conservation of Monuments. Dr. Bosh. 1st Int. Symp. on the Deterioration of Building Stones (September 11-16, 1972), Les Imprimeries Reunies de Chawbery, France, 1972, pp. 21-26.

Art monuments of stone are especially affected by rain water polluted by CO_2 , SO_2 , and nitrous fumes emitted by industry. Impregnation represents an efficient protection against the damages. Silicone is outstandingly suitable for the impregnation; it is water repellent, dirt repellent, highly permeable to gas, and prevents moss growth. But, if a stone is strongly decomposed, it should be strengthened first (silicic acid is best suited for this purpose). The latter procedure is described.

1971

1. Air Pollution by Sulfur Oxides. Staff Report. National Industrial Pollution Control Council, Washington, D.C., Report No. A2402F4, February 1971, 27 pp. (Fe71-2)
2. Atmospheric Pollution. S. Kups. *Double Liaison*, v. 18, 1971, pp. 825-828 (French).

A review covers the effects of solid (cement and metal), liquid, and gaseous (hydrogen sulfide, carbon monoxide, ozone, and hydrocarbons) pollutants on humans, plants, painted surfaces, and masonry.

3. Concrete in Sulfate Environments. E. G. Swenson. *Canadian Building Digest*, No. 136, 1971, 4 pp.

The rate and degree of sulfate attack depend on the concentration of sulfate present, the type and availability of sulfate ion, the accessibility of water, and the type of cement and quality of concrete. Preventive measures include the following: use of sulfate-resisting cement, low water-cement ratio, minimum cement content air-entrainment, waterproof coatings, drainage features, and special attention to reinforcing cover.

4. Conservation of Stone. T. Stambolov. Conservation of Stone and Wooden Objects, 2nd Ed., edited by G. Thomson, Intern. Inst. for Conservation of Historic and Artistic Works, v. 1, 1971, pp. 119-123.

The methods for cleaning and preserving stone are discussed.

5. Decay of Stone. E. M. Winkler. Conservation of Stone and Wooden Objects, 2nd Ed., edited by G. Thomson, Intern. Inst. for Conservation of Historic and Artistic Works, v. 1, 1971, pp. 1-14.

The sources of air pollutants, such as CO_2 , SO_2 , SO_3 , NH_3 , NO_3 , and Cl^- and the effects of soot and dust in neutralizing acid rain are discussed. Plants and animals, bacteria, etc. are also discussed. The mechanism by which stones decay and the effects of the various pollutants on this decay are discussed.

6. Notes on the Deterioration of Donatello's Marble Figure of St. Mark on the Church of Orsan Michele in Florence. U. Plahter and L. E. Plahter. Studies in Conservation, v. 16, 1971, pp. 114-118.

Chemical analyses of the surface crust found on the marble was calcium sulfate, carbon black and iron oxide. X-ray diffraction analyses showed the presence of gypsum, calcium oxalate hydrate, some quartz and possibly hematite. The crust is most probably a corrosive later formed on the statue under the influence of dust, water and sulfur dioxide.

7. Role of SO_2 in Atmospheric Corrosion. D. J. Spedding. Chem. Ind., v. 2, No. 6, 1971, pp. 39-41. (Fe71-20)

8. Stone Preservation in Germany. J. Riederer. Conservation of Stone and Wooden Objects, 2nd. Ed., edited by G. Thomson, Intern. Inst. for Conservation of Historic and Artistic Works, v. 1, 1971, pp. 125-134.

This paper discusses the relationship between damage and the type of stone. The cause of damage such as freezing, rising damp, rain, bacteria, sulfates, chlorides and nitrates are also discussed. Methods for removing damaged material and preservation are covered in some detail.

9. The Conservation of German Stone Monuments. J. Riederer. Proc. of the Meeting of the Joint Committee for the Conservation of Stone, Bologna, 1971, pp. 105-138.

This paper is designed to convey a general idea of how the stone conservation problem is being tackled in Germany. By means of accurate preliminary studies of the decaying stone, the crystallizing salts, the amount of humidity, and the action of bacteria, the deterioration forces can be recognized. The prevention of the action of these deteriorating forces is essential for the success of the conservation. Natural weathering, crystallizing salts from the ground moisture, and the action

of bacteria are the most frequent causes of the decay of stone. Air pollution does not considerably influence the decay of stone, especially compared with the effect of natural weathering. For the conservation of stone, synthetic resins and waterglass were first used. Now the application of silicate esters, which have proved to be much more effective, has increased notably.

10. The Destruction of Works of Art by Air Pollution. J. Riederer. *Schonere Heimat*, v. 60, 1971, pp. 44-47 (German). (Cu71-10)

11. The Stone Features in the Palace of Lazienki, Their Present State and Preservation Problems. B. Penkala and K. Paczek. *Rocznik Muzeum Narodowego w Warszawie*, v. 15, Pt. 2, 1971, pp. 405-444 (Polish).

A general description of stone features in the King's summer palace of Lazienki (Warsaw) is followed by a description of the properties of the particular kinds of stone: macro- and micro-structure, and physical and mechanical characteristics. The present condition of the stones, causes of deterioration, and protection against further corrosion are considered.

12. The Weathering of Tombstones And Its Relationship to the Topography of New England. P. H. Rahn. *J. Geological Education*, v. 19, No. 3, 1971, pp. 112-118.

Students divided tombstones in the West Willington, Connecticut, cemetery into six weathering classes. Analysis of the data, corrected to a common tombstone age of 100 years old, shows that: (1) granite is virtually unweathered, (2) schist is usually only slightly weathered, (3) marble weathers rapidly and uniformly, and (4) red (Triassic) sandstone weathers fastest.

1970

1. Atmospheric Pollution and Historic Buildings. A Contemporary Urban Problem. C. Berindan. *Centre Belged'Etude et de Documentation des Eaux (Tribune de)*, v. 23, No. 324, November 1970, pp. 498-503 (French). (Fe70-4).
2. Effects of Aggressive Solutions on Ordinary Portland, Sulfate-Resisting Portland, and Frodingham Supersulfated Cement Concretes. G. H. Thomas. NTIS Report PB-188759, 1970, 13 pp.*

Results of 10 years of tests to assess the comparative resistance of ordinary portland cement, sulfate-resisting portland cement, and Frodingham supersulfated cement concretes to a wide range of aggressive solutions are recorded. Both the sulfate-resisting portland cement and the slag based supersulfated cement showed good resistance to most of the

solutions. Concrete specimens made from the supersulfated cement gave the best overall performance, displaying a particular advantage over both portland cements in weak H_2SO_4 and strong Na_2SO_4 solutions.

3. Effect of Corrosive Solutions on Adhesion of Acid-Resistant Mortars.
S. Pawlikowski, I. Pollo, and M. Starczewski. Zesz. Nauk. Politech. Slask., Chem., No. 50, 1970, pp. 241-243 (Polish).

Ceramic slabs were bound with three kinds of mortars by using quartzite flour, water glass, and Na_2SiF_6 . After 21 days of setting the specimens were placed for 42 days in different corrosive media. The adhesiveness of the mortars fell to 0 in flowing water, to 5.4-8.3 kg/cm^2 in stagnant distilled water, to 1-5 kg/cm^2 in 20-92 percent H_2SO_4 , and 2.5-7.3 kg/cm^2 in 30 percent H_3PO_4 . The destructive effect of aqueous HNO_3 , HCl , and NH_4NO_3 was much weaker.

4. Removal of Atmospheric Sulfur by Building Stones. R. C. Braun and M. J. G. Wilson. Atmos. Environ., v. 4, No. 4, 1970, pp. 371-378.**

Measurements were made of the amounts of sulfur absorbed by limestone from outdoor air and from SO_2 -air mixtures in the laboratory. A limestone, which had been exposed for 5 centuries, could still absorb sulfur as fast as a new sample of the same kind of stone. The distribution of sulfur in old stones suggested that their activity had been maintained by rain washing. The results are used to discuss the effect of absorption in cleaning city air.

5. Stone Preservation in Germany. J. Riederer. Conservation of Stone and Wooden Objects, Contributions to the New York Conference, June 1970, pp. 125-133.

The first part of this paper is a detailed investigation of the nature of the damage. The factors which were considered to affect corrosion are: the grain size of the stone, the salt distribution in rocks, the moisture content. The second part investigates the causes of the damage which were cited as: the salts (especially the nitrates), sulfur dioxide, bacteria, sulfate ions, temperature, wind, mosses. The third part is about how to remove the damage: use of preservatives and determination of their usefulness.

6. Studies on the Deterioration of Sandstones of Some Monumental Buildings in Bologna. R. Rossi-Manaresi. Atti Academia Fisiocritic, v. 54, No. 2, 1970, pp. 285-305 (Italian).

The extensive chemical analysis of the soluble fractions of surface crust, incoherent sub-surface and internal stone on the sandstones of several monumental buildings in Bologna is reported. X-ray diffractograms are also discussed and an interpretation of the deterioration process is presented.

7. Sulfate Resistance of Concrete. F. Jung. Cement (Zagreb), v. 14, No. 3, 1970, pp. 125-130 (Croatian).**

The sulfate resistance of concrete is reviewed.

8. Systems Analysis of the Effects of Air Pollution on Materials.
R. L. Salmon. NTIS Report PB-209 192, January 15, 1970, 196 pp.
(Fe70-13)
9. Testing and Estimation of the Resistance of Cements to Sulfate Attack. H. Steinegger. Zem-Kalk-Gips, v. 23, No. 2, February 1970, pp. 67-71.

To estimate the serviceability of the rapid testing method using small prismatic specimens, as described in the article, long-term tests on concrete were performed in parallel with the rapid tests. The two test series gave good agreement in the estimation of the cements. With the rapid testing method, it is possible to arrive at an assessment of the sulfate resistance of a cement after 77 days.

10. The Importance of Air Pollution in the Corrosion of Stone and Metals.
E. M. Winkler. Eng. Geol. (Amsterdam), v. 4, No. 4, October 1970, pp. 327-334. (Fe70-14)
11. The Weathering and Performance of Building Materials. J. W. Simpson and P. J. Horrobin, eds., Medical and Technical Publishing Co. Ltd., 1970, 277 pp. (Fe70-17)

1969

1. Determination of the Sulfate and Acid Resistance of Concretes by Field Experiments. I. Medgyesi and G. Toroczky. Durability Concrete, Int. Symp., Prelim. Rep., v. 2, 1969, pp. C283-C299.**

Hungarian concrete was examined after prolonged immersion in natural water, water polluted by industrial waste, and acidic waste water. The conclusions are: natural water with up to 8,000 mg sulfate/l is destructive after 2 years. Samples show more resistance with higher cement content. A high slag content concrete has less resistance. Residual water permeating on acidic soil destroys reference samples in 2 years. Acidic water flowing in concrete ducts degrades samples in 6 to 8 months.

2. Effects of Sample Volume: Solution Volume Ratio on the Determination of the Resistance of Mortars to Sulfate Corrosion. C. Solacolu and A. Vasiliu. Rev. Mater. Constr. Taruv. Pub., v. 21, No. 9, 1969, pp. 490-492 (Romanian).

Mortar samples (2 x 2 x 12cm) of Romanian cement RIM 250 were prepared with 87.8 kg/cm² flexural tensile stress, 515 kg/cm² compression strength at 28 days, and 11.4 percent water absorption. Tests were carried out at sample volume/5 percent sulfate solution volume ratios of 1:2, 1:10, and 1:20. Readings of mechanical strengths were made monthly for 12 months; the characteristics of the sulfate corrosion did not change and the lesser the sample volume/solution volume ratio, the faster its effect.

3. Immersion Tests on the Sulfate Resistance of Concrete. B. Steele and W. Harrison. *Durability Concrete, Int. Symp., Prelim. Rep., v. 2, 1969, pp. C163-C186.***

Several laboratories are cooperating in a 20-year program of tests to assess the sulfate resistance of 100 mm concrete cubes after immersion in various sulfate solutions. The rate of deterioration of the concrete specimens is assessed by comparison of the compressive strength of the cubes compared with that of a similar water-stored cube of the same age. The program also includes the visual assessment of concrete columns half immersed in the solutions. The position at the end of the first five years of the program is presented, and the detailed results obtained from the tests carried out after 5-year immersion are discussed.

4. Sulfur Dioxide Uptake By Limestone. D. J. Spedding. *Atmos. Environ., v. 3, No. 6, 1969, p. 683.***

A comparison of a photograph of a limestone surface with a number of fossil inclusions with an autoradiograph of the surface after exposure to 100 ug of SO₂/m³ in air for 1 hour at 70 to 80 percent relative humidity indicated that the SO₂ was taken up by the limestone matrix and not by the fossils. The solution and erosion of the matrix as CaSO₄ left the fossil area raised and the matrix exposed to further attack. A laser microprobe showed the chemical nature of the fossils and the matrix to be identical and the differential uptake of the SO₂ to be based on the physical differences of the fossil and the matrix surfaces. Autoradiographs of oolitic limestone at 79 to 81 percent relative humidity exposed to 100 to 370 ug of SO₂/m³ showed 4 times the uptake of SO₂ as with 11 percent relative humidity. Freshly exposed matrix surface could saturate at normal atmospheric humidities and the erosion associated with the formation of CaSO₄ would be virtually continuous for the matrix.

1968

1. Decay of Plaster, Paintings, and Wall Material of the Interior of Buildings via Microbial Activity. W. E. Krumbein and C. Lange. Chapt. in *Biodeterioration of Materials: The Terrestrial Environment*, edited by A. H. Walters and E. H. Hueck-Van der Plas, v. 2, Halsted Press Division, John Wiley, New York, N.Y., 1968, pp. 687-697.

Early in the period of the Industrial Revolution and technical civilization, in terms of the high energy consuming western European and North American technology, it was stated that in contrast to any other technology prior to the present one the increased rate of decay of cultural treasures is a still growing danger. Kieslinger, Winkler, and Weber have stressed that decay of building stones is a natural phenomenon which has always endangered human stone constructions, objects of art and mineral paints. This can be shown by early reports by Moses and Herodatus. On the other hand there is no doubt that the industrial revolution, with its deep influence on biogeochemical cycles and geomicrobiological processes, has accelerated stone decay and added new dimensions to the problem.

2. Durability of Concrete Construction. H. Woods. American Concrete Institute, Monograph No. 4, Detroit, 1968, 167 pp.

Chapter 8, "Chemical Effects on Concrete", discusses sulfate attack on concrete in both gaseous and aqueous environments and the effect of various pH levels of soils and ground water on durability. Results of several long-term exposure testing programs are reported.

3. Effect of Sulfur Pollution on Building Materials. T. Stambolov. Proc. 1967 London Conference on Museum Climatology, published by IIC, 1968, pp. 15-22.

The aggressiveness of air pollution, particularly gaseous SO_2 , and its various mechanisms are discussed in reference to some of the deteriorations observed on the walls of museums, churches and monuments. The effects of in situ hydration of various sulfates on calcareous and other materials is also discussed.

4. Microorganisms and Weathering of a Sandstone Monument. F. E. W. Eckhardt. Biodeterioration of Materials: The Terrestrial Environment, edited by A. H. Walters and E. H. Hueck-Van der Plas, v. 2, Halsted Press Division, John Wiley, New York, N.Y., 1968, pp. 675-685.

Weathering of stone in buildings and monuments will proceed more or less quickly due to such well known environmental agencies as temperature, humidity or salt concentration. In addition, the microbial population of the stone may also contribute to its decay. The presence of microorganisms, even in great numbers, on weathered material does not necessarily imply that these organisms have caused the damage observed; however, these populations may be involved in enhancing abiotic processes. Since the activities of microorganisms are suspected to be an important factor in the weathering of building stones, the present work was undertaken to find out whether the decay of a 150-year-old sandstone obelisk could be related to activity of its microbial population.

1967

1. Corrosive Action of Ammonia and Carbon Dioxide on Concrete Treated in an Autoclave. Y. M. Butt, K. K. Kuatbaev, and P. A. Roizman. Wiss. Z. Hochsch., Bauw., Leipzig, v. 13, No. 4, 1967, pp. 13-18 (German).*

Experimental work is given that involved the determination of the effect of NH_3 on the promotion of carbonization of concrete building components hardened by autoclaving. Various types of concretes were examined. Their compositions are given. The conclusion is that concrete of the type $2\text{CaO-SiO}_2\text{-H}_2\text{O}$ ($\text{C}_2\text{SH(A)}$) carbonizes rapidly in the presence of NH_3 . The presence of NH_3 in the surrounding media causes the formation of NH_4 silicate and aluminate gels, causing a lowering of the strength of cellular concretes. The instability of carbonized cellular concretes is increased by storage in an NH_3 containing atmosphere. When erecting concrete structures in an NH_3 containing atmosphere, no material should be used that could form $\text{C}_2\text{SH(A)}$. In order to lessen the deleterious effect of NH_3 on autoclave hardened concrete components, they should be nonporous or protected by vapor barriers.

2. Corrosion by Air Pollution. J. R. Goss. Proc. Annu. Conf., Nat. Soc. Clean Air, No. 34, 1967, pp. 75-92. (Fe67-4)
3. Weathering Rates of Portland Arkose Tombstones. G. F. Matthias. J. Geological Education, v. 15, No. 4, 1967, pp. 140-144.

Old cemeteries offer fertile ground for studies in weathering rates of stone materials. Portland arkose, a Triassic sandstone, was widely used in central Connecticut as a material for gravestones during the 18th and 19th centuries. The depth of inscription on these stones was used to measure the extent of weathering. Examination indicates that the tombstones have been weathering at an average rate greater than $2/64\text{th}$ inch over a 145-year period but that there has been a three-fold increase in the rate of weathering since the turn of the century. Weather information suggests an increase in the annual temperature since 1900 which, along with the increase in CO_2 content of the atmosphere, is probably responsible for the increase in rate.

1966

1. Corrosion Rates of Carbonate Rocks for Construction. E. M. Winkler. Eng. Geol. (Sacramento), v. 3, No. 1, 1966, pp. 52-58.

Carbonate equilibria in waters is reviewed. The Langelier saturation index and the Baylis saturation curve are compared. The latter is more convenient to use.

2. Important Agents of Weathering for Building and Monumental Stone.
E. M. Winkler. Eng. Geol. (Amsterdam), v. 1, No. 5, 1966, pp. 381-400.

The atmosphere has little corrosive effect on stone without the presence of water. Washout of aggressive ingredients from the atmosphere by rainwater, however, increases corrosion and solution of stone. Dissolved CO_2 , SO_2 , SO_3 , and Cl are the most effective corrodants. The urban atmosphere supplied much more CO_2 and sulfates through the combustion of fossil fuels than the atmosphere of rural areas; this accelerates stone decay in urban areas very much. Water with few ions in solution may be as corrosive as CO_2 and SO_4 charged water, as it must eventually reach the equilibrium condition with the stone it contacts. Silicate rocks can resist exposure to rainwater successfully for a long time. Exposure of facing stone and concrete aggregate to soft or acid running water or lake waters causes damage primarily to carbonate rocks. Resistant silicate rocks should be selected.

Primitive animals and plants may inhabit bare stone surfaces paving the way to more extensive destruction through the production of organic acids along the root system. All rocks are subject to attack by the lower animals. Boring sponges, sea shells, and sea urchins may develop a dense network of pock marks near the waterline in different rock types; This occasionally happens also in concrete.

3. The Preservation of Natural Stone, 1839-1965. S. Z. Lewin. Art Arch. Tech. Abst., v. 6, No. 1, 1966, pp. 183-277.

Despite more than a century of experimentation, investigation and field testing, the problem of inhibiting, arresting or preventing the deterioration of natural stone remains largely unresolved. This is perhaps to be expected for the classification "stone" embraces a range of materials manifesting very diverse physical and chemical properties, and the deterioration of stone occurs through a variety of mechanisms which may proceed independently, consecutively, simultaneously, or cooperatively.

Among the factors to which attention has been called as playing an important role in stone decay are: (a) the mechanical action of wind-borne particles, of thermal cycling, of freezing of imbibed water, of crystallization of salts; and of the growth of plants; (b) the chemical action of liquid water or salt solutions, of acidic constituents in the atmosphere, and of the metabolic processes of lichens, algae and bacteria; and (c) the inherent defects associated with faulty construction, incorrect orientation of bedding planes relative to the loading direction, and inappropriate combinations of materials.

There is much disagreement in the literature as to the relative importance of these various factors under actual field conditions. Some authorities declare that air-borne sulfur dioxide is the principal cause of the decay of limestone; others assert that this is of minor significance, but that carbon dioxide dissolved in rain water is the chief culprit. Bacteria and algae and lichens are claimed by some to play the dominant role whereas others maintain that the presence of these organisms is either irrelevant to, or only a secondary result of, stone decay. The mechanical effect of frost is considered to be the driving force leading

to all the other manifestations of stone decay be certain writers whereas other focus attention on the leaching and mass transport effects of liquid water or on the mechanical stresses accompanying the formation of salt efflorescences. Abstracts of available literature from 1865-1965 are included.

1965

1. The Weathering, Preservation and Maintenance of Natural Stone Masonry, Part I. Building Research Station Digest, No. 20, July 1950, revised March 1965, 7 pp.

The surface deposits on sandstones and granites are very hard and, being insoluble in water, are extremely difficult to remove, whereas the surface films on limestones, though hard and intractable in the dry condition, can be softened and removed with water.

Calcium sulfate tends to form a hard, glossy skin on limestone wherever the stone is not freely washed by rain. This sulfate skin tends to be harmful rather than protective. Some varieties of stone offer a good resistance; with others, skin formation leads to a spontaneous blistering and scaling of the surfaces. Cracks develop at the arrises and active centres of decay make themselves apparent where the surfaces are broken. Elsewhere, the hard surface may be found to overlie a layer of friable stone. Sometimes scabby protuberances appear, even on well-exposed surfaces. Calcareous sandstones are subject to similar defects. The precise mechanism by which this form of decay occurs is still not fully understood, but the signs are unmistakable. It may be taken as axiomatic that contamination of porous building stones with soluble salts of any kind is liable to cause damage to the stone.

1964

1. Atmospheric Microorganisms in the Shosoin at Nara With Special Reference to the Filamentous Fungi. E. Yoshikadzu. Science for Conservation (Tokyo), No. 1, 1964, pp. 7-22 (Japanese, with English summary).

The writer conducted an investigation on fungi at six locations near the Shosoin in conjunction with other investigations on air pollution, by sampling, making cultures and identifying species. Investigation was also made of the dust at eight locations in the East Treasury which is made of concrete, and at six locations in the Shosoin treasury. Fifty-seven species were identified though there were many others that could not be identified because they did not show generative organs. *Penicillium*- and *Aspergillus*-spp. were predominant while *Cladosporium herbarium* and *Cladosporium* spp. were also found. The latter two are dangerous because they leave black spots. Seasonally, April and November are the most dangerous months for fungus growth.

1963

1. Corrosion of Cements in Sulfuric Acid. T. A. Atakuziev and I. S. Kantsepol'skii. Nekotorye Vopr. Khim. Tekhnol., i Fiz-Khim. Analiza Neorgan. Sistem. Akad. Nauk Uz. SSR, Otd. Khim. Nauk, 1963, pp. 5-13 (Russian).*

Sulfuric acid (0.1N solution) corroded porous cement solutions after 28 days; complete destruction of cements appeared after 6 months. Corrosion of cements with active mineral additives was quicker than corrosion of additive-free portland cement. Considerable corrosion in 0.01N H_2SO_4 was found only after 1 year. A bending test revealed that in 0.1N H_2SO_4 solution samples were corroded mainly in the first 28 days, and then the corrosion rate decreased considerably; in 0.01N H_2SO_4 solution, samples hardened in the same way as in distilled water. The process of corrosion, studied by means of differential thermal analysis (DTA) ($CaSO_4 \cdot 2H_2O$ served as the standard sample), showed that after 1 year leaching in 0.5N H_2SO_4 solution the acid penetrated to a depth of 7 mm in the case of cement sand and to a depth of 3 mm in the case of dense cement stone, the resulting sediment and surface crust being formed by hydrated gypsum as proved by DTA, X-ray analysis, and chemical and petrographic analyses.

2. Corrosion of Concrete Reinforcing Subjected to Corrosive Action. V. Moldovan. Rev. Mater. Construct. Taruv. Pub., No. 570, 1963, pp. 98-99 (French).

The effect of variables, other than concrete cover thickness, on the resistance of steel bars to corrosive waters was studied. The bars were 12, 20, and 30 mm in diameter in cylindrical concrete specimens of uniform concrete cover thickness of 15-40 mm. The aggregate was of continuous grain size distribution, maximum grain 15 mm, except for a few monogranular specimens 3-7 mm. Concretes were of plastic consistency except for a few fluid concretes. Additives of clay (2-6 weight-percent aggregate, as films on grains or as powder plasticizers), humic acids (0.35, 0.7, and 1.5 Percent of the cement), surfactants (Calignosulfonate, Na butylnaphthalene sulfonate, and Vuzal from Czechoslovakia), and $CaCl_2$ were tested. Specimens were stored 1 day in molds, 6 days in water, 83 in air, then either in 2 percent NaCl solution (to 3/4 their depth) or in a moist NH_3 atmosphere. After 12 months exposure, specimens with fissures less than 0.5 mm showed no ruts, but after 24 months, NaCl corroded the reinforcing in all fissured specimens. Ammonia corroded the most fissured specimens and those nonfissured ones containing clay or only a thin cover. All plastic concretes with 380 kg cement/ m^3 protected the reinforcing bars; those with 240 kg required a 20-mm (in minimum) cover for protection. Humic acids and surfactants were favorable, causing a reduction in the water-cement ratio. Fluid concretes, insufficiently compacted plastic concretes, and concretes without sand gave no protection.

3. Effect of Air Pollution Upon Cultural Property. E. Yoshimichi. Sci. Papers Japan. Antiques, No. 17, 1963, pp. 23-31.

With the rapid development of industry in Japan, the problem of air pollution calls for an urgent solution. This article is a commentary on types of pollutants, their effects on art objects, and methods for protecting them. Examples are given of damage caused by air pollution in Japan.

4. Leaching of the Cement Portion During Weathering of Concrete.
G. Larsen. Nord. Betong., v. 7, 1963, pp. 203-220 (Danish).

Weathering of concrete was caused predominantly by the leaching of the cement portion by the entry of water. The reaction between alkalies and silicic acid caused cracks, accelerating the leaching process. The Ca(OH)_2 formed CaCO_3 in air; with sea water it reacted to form Mg(OH)_2 and caused blooming. Sulfur dioxide from air and from sea water caused the formation of Calcium sulfoaluminate. Freezing and thawing cycles accelerated the leaching.

5. Scientific Preservative Methods for Cultural Properties. V. Air Pollution. I. Tomokichi. Museum (Tokyo), No. 143, 1963, pp. 28-29.

Effects of smog, dust, and toxic gases like sulfur dioxide are discussed.

6. Ten-Year Test Results on the Sulfate Resistance of Concrete. R. Nagano. Semento Gijutsu Nempo, v. 17, 1963, pp. 400-410 (Japanese).**

Tests were made on concrete specimens containing various types of portland cements ($3\text{CaO}\cdot\text{Al}_2\text{O}_3$ 5-12 percent) and blended cements containing slag, fly ash, and diatomaceous earth, with or without air-entraining agents. After curing in H_2O for 7 days, the specimens were immersed in 10 percent Na_2SO_4 or $\text{Na}_2\text{SO}_4 + \text{MgSO}_4$ (2:1) solutions. Rich-mix concrete containing $3\text{CaO}\cdot\text{Al}_2\text{O}_3$ -less portland cement and blended cements were resistant. The addition of air-entraining agents was not so effective, and some agents decreased the resistance, so the selection of the agents is important.

1962

1. Behavior of Hydrated Cement Minerals Under the Action of Corrosive Types of Water, Considered With Reference to Concrete Corrosion.
A. Kjennerud. Nord. Betong., v. 6, No. 3, 1962, pp. 223-234 (Danish).

The present paper deals with the behavior of hydrated cement minerals under the action of CO_2 corrosive aqueous solutions. The solutions were synthesized on the basis of analyses of ground water from areas where damage to concrete had been observed. The hydrated cement minerals were synthesized from the pure clinker minerals. After about 30 days the products were investigated by means of X-rays to identify the phases.

Microscopical examination was undertaken to determine the texture of the mineral aggregates. The hydrated minerals were separately subjected to repeated extraction by the CO_2 -corrosive solutions. The extraction curves show that the aluminates are considerably more resistant than the silicates at a moderate content of corrosive CO_2 and a low concentration of sulfate.

2. Chemistry in the Service of Archaeology, Building Technique and Monuments Conservation. J. A. Hedvall. Akademiforlaget-Gumperts, Goteborg, 1962, 226 pp. (German).**

Hedvall considers the natural sources of degradation of materials and emphasizes the use of all available instrumentation to learn chemistry, petrography, physical properties, and geological origin of building materials. Information is given on natural and manmade building stone, pottery, glass, precious natural and manmade stone concerning chemistry, mineralogy, crystallography and texture. Natural causes of degradation are listed and analyzed including: air pollution, weathering, wind erosion, radiation, water table, humus acids, carbon dioxide, bacteria and fungi; corrosion due to contact of different materials such as granite or marble and steel; frost and frost-bite, or fire; errors of construction; and plant attack by algae and lichens.

3. Corrosion of Ceramic Products by Gases Containing Sulfur. C. Bardin. Ind. Ceram., No. 544, 1962, pp. 341-347 (French).

The problems of efflorescence, attack on glazes, and the corrosion of ceramic installations by gaseous SO_2 , SO_3 , and H_2SO_4 are reviewed. Knowledge of the dew points of the gases permits corrective action to minimize the corrosion.

4. Durability of Concrete in Service. Committee Report. Committee 201, American Concrete Institute, Detroit, No. 59-57, 1962, 44 pp.

Chapter 3 discusses aggressive chemical agents. Most corrosive chemicals, to produce significant attack on concrete, must be in solution form and above some minimum concentration. Concrete is rarely, if ever, directly attacked by solid, dry chemicals. Concrete which is subjected to aggressive solutions under pressure on one side is more vulnerable than otherwise because the pressures tend to force the aggressive solution into the concrete. When free evaporation can also take place from an exposed face, dissolved salts may accumulate at that face, thus increasing their concentration and possibly resulting in mechanical damage from spalling in addition to chemical attack.

It is recognized that no portland cement concrete, regardless of what may be its other ingredients, will long withstand water of high acid concentration. Where strong acid corrosion is indicated, an appropriate surface covering or treatment must be used.

Two different conditions must be recognized.

1. Those in which proper attention to the concrete itself will provide immunity or an acceptably low rate of attack, and

2. Those in which it is necessary to prevent contact between the aggressive chemical and the concrete by means of a protective coating. For specific recommendations concerning protective coatings where needed, consult report of ACI Committee 616, "Coatings for Concrete," in preparation. Also consult Portland Cement Association Publication "Effect of Various Substances on Concrete and Protective Treatments, Where Required."

1961

1. The Weathering, Preservation and Maintenance of Natural Stone Masonry, Part III. Building Research Station Digest, No. 21, August 1950, reprinted 1961, 8 pp.

Lichens and mosses are found on building stones in country districts where the level of atmospheric pollution is not high enough to inhibit their growth. Only occasionally are they found to cause any perceptible harm to the surfaces on which they grow. Ivy sends out aerial roots which cause severe damage if they secure a foothold in the joints. Virginia Creeper, which attaches itself by means of suckers, causes no appreciable harm unless it is allowed to grow into gutters and roof tiling.

There is as yet no proof that nitrifying bacteria or sulphur bacteria play any significant part in the processes of decay in building stones. There has certainly been no demonstration that antiseptic treatment of the stone will preserve it from decay. Although there has been a long-standing demand for some form of treatment that will improve the weathering behaviour of the less durable kinds of stone without detracting from their appearance, experience in the use of such treatments, extending over the past 100-200 years, has been disappointing. Some tend to disappear without causing any apparent effect, good or bad; some hold soot and dirt, causing the stone to become discoloured and shabby; some will harden and consolidate friable surfaces, but the depth of penetration that can be secured by a surface application is always limited and there is then a risk that the consolidated face may scale off, leaving the stone in a worse condition than before.

2. The Weather Stability of Lime-Ash Cements. Y. M. Butt, B. G. Varshal, and A. A. Maier. Sb. Tr., Resp. Nauchn.-Issled. Inst. Mestnykh Stroit. Materialov, No. 20, 1961, pp. 3-17 (Russian).

At ordinary temperatures in lime-shale ash or lime-brown coal ash mixtures (for example, 80:20) in the presence of gypsum (5%) are formed $3\text{CaO} \cdot \text{Al}_2\text{O}_3 \cdot 3\text{CaSO}_4 \cdot 31\text{H}_2\text{O}$, or in the absence of gypsum, $4\text{CaO} \cdot \text{Al}_2\text{O}_3 \cdot 13\text{H}_2\text{O}$. Calcium hydrosilicates and CaCO_3 appear in the process of later setting. Teaming causes the formation of $3\text{CaO} \cdot \text{Al}_2\text{O}_3 \cdot 6\text{H}_2\text{O}$ or, in the presence of gypsum, the solid solution $4\text{CaO} \cdot \text{Al}_2\text{O}_3 \cdot 13\text{H}_2\text{O} - 3\text{CaO} \cdot \text{Al}_2\text{O}_3 \cdot \text{CaSO}_4 \cdot 12\text{H}_2\text{O}$, and in addition, calcium hydrosilicates. With autoclave treatment, calcium hydrosilicates of the type of the hydrogarnet $3\text{CaO} \cdot \text{Al}_2\text{O}_3 \cdot n\text{SiO}_2 \cdot (6-2n)\text{H}_2\text{O}$ appear and hydrosilicates of the group in which SiO_2 is in part replaced by Al_2O_3 . The weather stability of the newly-formed hydrates is determined by their resistance to moist CO_2 , which is satisfactorily

attained by autoclaving. Alternate wetting and drying do not lower the strength of lime-ash products. A sharp change in the phase composition of the hardened material due to the reorganization of the crystal lattice of the newly-formed substances is coincident with a drop in strength. If an isomorphic exchange with calcite occurs, the strength does not decrease but may even rise. In the case of weather-resistant lime-tripoli cements, it is essential that the tripoli shall enter into complete combination with the newly-formed substances since the unbound tripoli, with alternate wetting and drying, changes volume so greatly as to cause disintegration of the structure. Fine grinding promotes such interaction.

1960

1. Building Corrosion in the Nonferrous Industry. N. P. Shalamov. Prom. Stroitel., v. 38, No. 2, 1960, pp. 5-12 (Russian).

Contamination of the atmosphere was studied in plants for Al and Mg reduction, Ti chlorination, and Cu smelting, both for summer and winter operation, at different levels of the buildings. The effect of F, HF, Cl, HCl, and SO₂ on concrete is examined.

2. Corrosion and Protection of Limestone Monuments. J. Kauffmann. Corrosion AntiCorrosion, v. 8, 1960, pp. 87-95.*

The purpose of the investigation was to determine the mechanism of destruction of limestone monuments and to find a method for their protection. It was found that destruction is due to the attack by HNO₃ generated by nitrifying bacteria, and the protection therefore consists of providing conditions unfavorable for the development of bacteria.

3. Research on the Performance of High-Voltage Insulators in Polluted Atmospheres. J. S. Forrest, P. J. Lambeth, and D. F. Oakeshott. Proc. I.E.E.E., v. 107, pt. A, 1960, pp. 172-187.

The paper describes the work which has been carried out at the Croydon Insulator Testing Station during the last 15 years on the performance of insulators in humid and polluted atmospheres. Various types of line and substation insulators have been investigated, and the results obtained with insulators for working voltages of up to 380kV are presented. Methods of surface treatment to improve insulators performance are also discussed. Work on experimental insulators made from plastics is described. An account is given of recent work on insulators for high-voltage d.c. operation. The use of artificial salt-pollution tests to simulate service conditions is also discussed.

1959

1. A Method for the Identification of Sulfates and Their Dispersion in Weathered Natural Building Stones. H. Galle. Wissenschaftliche Zeitschrift der Hochschule fur Bauwesen Cottbus, v. 2, 1958/1959, pp. 129-131 (German).

The presence of sulfates and their dispersion is proven by the color reaction in stone slides tested with barium rhodizonate.

2. Deterioration of Materials in Polluted Atmospheres. J. E. Yocum. Corrosion, v. 15, No. 10, October 1959, pp. 541t-545t. (Fe59-5)
3. Technical Examinations of the Stones Used in the Monument Commemorating the Battle of the Nations at Leipzig, With Special Consideration of General and Local Influences. H. Galle. Wissenschaftliche Zeitschrift der Hochschule fur Bauwesen Cottbus, v. 2, 1958/1959, pp. 15-26 (German).

The monument was completed in 1913 of pyroxene-granite-porphry and concrete. Examinations were made of this building which is still in the early stages of weathering. The results show that urban influences are preponderant. However, further elaborations show that special climatic influences of the same stones will lead to varying weathering manifestations on various parts of the building.

4. The Resistance of Ferritic Portland Cement to Sulfates. P. E. Shevyakov and I. S. Kantsepol'skii. Uzbek. Khim. Zhur., No. 2, 1959, pp. 76-83 (Russian). **

A ferritic portland cement was prepared, having the following composition: SiO_2 21.94; Al_2O_3 0.85; Fe_2O_3 11.75; CaO 62.99; MgO 0.32; SO_2 0.36; free CaO 0.80; insol. 0.38 percent. Three percent of $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ was introduced. Testing specimens in the form of prisms having the ratio 1:3.5 cement to sand and dimensions 1x1x3 cm were formed and immersed in 3 percent Na_2SO_4 solution. The strength of the specimens as compared to those immersed in water after 1, 3, 7, 14, 28, 45, 60, 120, and 180 days was determined. For comparison purposes, tests with aluminate and aluminoferritic cements were run. It was confirmed that the sulfate aggression of the cements containing Ca aluminates is caused by the crystallization of Ca hydrosulfoaluminate. The crystallization of gypsum causes much smaller internal deformations. Gypsum (20 percent) was crystallized and more than 20 percent lime was leached out from the ferritic cement by the 3 percent solution of Na_2SO_4 . Nevertheless, the ferritic cement retained a greater stability than the alumina cement, which is quickly destroyed by adding 8 to 9 percent gypsum to calcium hydrosulfoaluminate.

5. Use and Durability of Natural Building Stones on Buildings in Leipzig.
H. Galle. Wissenschaftliche Zeitschrift der Hochschule für Bauwesen
Cottbus, v. 2, 1958/1959, pp. 133-146 (German).

Several building periods were identified by various building stones. The first phase of local materials of technically minor value was followed by the widespread use of tufaceous porphyry from Rochlitz. Since the middle of the 19th century, sandstone from Saxony, shell limestone, travertine and others were used. Comprehensive weathering studies of the materials, considering the local conditions, show excellent wear, besides the indestructible hard rocks, of shell limestone and travertine, and good durability of the tufaceous porphyry, but variable conditions among the sandstones, even within their various types.

1958

1. Chemical Damage of Concrete and Its Prevention. H. Schaffler. Gas u. Wasserfach 99, 1958, pp. 1001-1005 (German).

A review is given of concrete damage by water and solutions, with photographs of several types of damage. Methods of preventing such damage are evaluated.

2. Durability Tests of Structural Sandwich. E. W. Kuenzi and L. W. Wood. Symposium on Some Approaches to Durability in Structures, American Society for Testing and Materials, ASTM STP 236, 1958, pp. 27-34. (Fe58-4)
3. Effect of Production Features on Building Construction of Titanium-Magnesium Plants. V. N. Romanov. Legkie Metally (Leningrad) Shornik, No. 1, 1958, pp. 34-40 (Russian). (Fe58-5)
4. Effect of the Atmosphere on Masonry and Related Materials. J. W. McBurney. Symposium on Some Approaches to Durability in Structures, American Society for Testing and Materials, ASTM STP 236, 1958, pp. 45-56.

Except for corrosion of metals, rather little attention has been given to air as a possible factor in disintegration of structural materials. The common assumption has been that all the deleterious substances which in time produce disintegration or excessive volume change in masonry were present originally in the units or in the mortar ingredients as delivered and used. This paper considers the effect on masonry of such components of the air as carbon dioxide, alkali and alkaline earth salts, usually sodium, potassium, calcium and magnesium compounds, sulfur dioxide, and moisture as vapor expressed as relative humidity.

5. Laboratory Testing and the Durability of Concrete. T. B. Kennedy.
Symposium on Some Approaches to Durability in Structures, American Society for Testing and Materials, ASTM STP 236, 1958, pp. 14-26.

Concrete structures cannot be constructed and subjected to full-scale tests for durability in a manner analogous to load tests. It therefore is necessary to estimate the durability of concrete structures by combining information gained from a study of service yielded by existing structures, controlled exposure tests of specimens, laboratory simulated-service tests, and tests and analyses of concrete and concrete materials. None of these sources of information provide a basis for adequately evaluating the effect on durability of workmanship, honesty, and intelligence that may or may not be employed in all stages of the operation from production of concrete materials to maintenance of the completed structure.

Durability of concrete structures is determined by materials, workmanship, design, and exposure. Petrographic examination of aggregates, X-ray diffraction studies of cement, freezing-and-thawing tests of concrete both in the laboratory and at field exposure stations, ultrasonic pulse velocity tests of specimens and structures, are recommended means of improving knowledge of durability of concrete and concrete structures.

6. Some Factors Affecting Durability of Structural Clay Products Masonry.
P. V. Johnson and H. C. Plummer. Symposium on Some Approaches to Durability in Structures, American Society for Testing and Materials, ASTM STP 236, 1958, pp. 3-13.

Moisture penetration is a big factor in considering the surface disintegration, or decay, of masonry materials, regardless of the exact source or character of this decay. In consequence of this every means must be taken for preventing the penetration of moisture into the body of masonry from any source whatsoever, quite regardless of the character and durability of material employed.

1957

1. Corrosion of Concrete. T. Sneek. Nord. Betong., v. 1, 1957, pp. 117-127 (Danish).

The chemical and physical influences are discussed which produce the corrosion of concrete. Factors having an effect are the chemical composition, the quality of the starting material, and external factors. Heavy damage is caused by CO_2 and SO_2 from the atmosphere, especially from combustion gases. Water dissolves concrete, the substances dissolved in the water react with concrete, and impurities sometimes have a mechanical effect. The effect of pure water, and of water containing CO_2 , humus, and sulfate is discussed in detail. Swamp water, brackish, and salt water are especially dangerous. The effect of the soil with regard to its acidity is treated separately, and also some accessory constituents, such as organic acids, biological factors, and flora and fauna.

2. Corrosion of Concrete in Different Aqueous Media. M. Gruner. Gospodarka Wodna, No. 1, 1957, pp. 15-18 (Polish).

Very soft water containing free acids, soft water saturated with CO_2 , water containing sulfates of Ca, Mg, Na, or similar salts, or water containing several of the components referred to, causes corrosion owing to solution and gradual washing out of concrete components or to the formation of new chemical compounds which alter the structure of concrete. Factors determining the resistance of concrete to corrosion are chemical composition of cement (containing minute amounts of $3\text{CaO}\cdot\text{Al}_2\text{O}_3$), coarseness of cement (finely ground cement yields concrete of greater porosity and thus facilitates corrosion), and quality of concrete production, since all faults in production give access to the inside of concrete structures.

3. The Effects of Air Pollution on Buildings and Metalwork. R. J. Schaffer. Air Pollution, edited by M. W. Thring, Butterworth Scientific, London, 1957, pp. 58-71. (Fe57-5)

1955

1. Corrosion Aspects of Air Pollution. L. Greenburg and M. B. Jacobs. Amer. Paint J., v. 39, No. 43, 1955, pp. 64-78. (Fe55-2)
2. Destructive Effects of Air Pollution on Materials. A. Parker. Colliery Guardian, v. 191, No. 4937, October 13, 1955, pp. 447-450. (Fe55-3)

1954

1. Chemical Aspects of the Durability of Cement Products. T. Thorvaldson. Proc. Int. Symposium Chem. Cement, 3rd Symposium, London, (1952), 1954, pp. 436-484.

The available evidence concerning the effects of the compounds which may be present in portland cement on the resistance of mortars and concretes to the action of natural waters, particularly those waters containing sulfates, is summarized and discussed. The effects of pozzolans are also considered. Data are presented on the effect of sulfate solutions on the tensile strength and expansion of lean mortars made of ASTM type 1 and 5 cements. It is concluded that lean mortars are useful for determining the relative stability of cements, although they must be used with caution because of their variability between different experimenters. The addition of less than 2.5 percent of crystallized tricalcium aluminate to a sulfate-resistant cement destroyed its stability. The results of exposure of mortars to sulfate solutions for periods up to 22 years are given. Data on the effects on the long-time tests of steam-curing and of the substitution of active SiO_2 for part of the cement are presented and discussed.

2. Microstructure of Corroded Cement Solutions. B. S. Lysin and Y. E. Kornilovich. *Dopovidi Akad. Nauk Ukr. S.S.R.*, No. 2, 1954, pp. 123-127 (Russian).

Sulfates and CO_2 considerably decreased the mechanical strength of cement solutions. Microstructures of the corroded cements for each corrosive agents are specific. The cementographic method can be used for the investigations of different questions of corrosion of the cement solutions and concretes.

1953

1. Contaminated Fogs. N. Pilpel. *Research (London)*, v. 6, 1953, pp. 481-485.

The physicochemical nature of fog is discussed as a colloidal phenomenon. Methods of fog dispersal are described, including the use of surface-active agents. An illustration is shown of pollution damage to stone at Westminster Abbey.

2. Protection of Massive and Reinforced Concrete Structures from Acids. P. Lippold. *Die Technik*, v. 8, 1953, pp. 691-700 (German).

The most important chemical agents attacking concrete structures are HCl , H_2SO_4 , H_2SO_3 , HNO_3 , Cl , tannic, fatty, and fruit acids. With $\text{Ca}(\text{OH})_2$, present to some extent in all concretes, these acids form soluble salts, which can be washed out; this may destroy the structure. Protective coatings and linings for use in different industries are described.

1952

1. Role of Nitrifying Bacteria in the Alteration of the Calcareous Stone of Monuments. J. Kaufmann. *Compt. Rend., Acad. Sci., Inst. de France*, v. 234, 1952, pp. 2395-2397.

In addition to the sulfur-oxidizing bacteria of Pochon, it is proposed that some forms of stone decay are due to the activity of "nitrifying" bacteria. These bacteria convert atmospheric ammonia into nitrite and nitrate salts, which form efflorescences on the stone. The presence of these bacteria was demonstrated in specimens from Notre Dame, the church of Saint-Severin in Paris, and the cathedrals of Vienne and Romans (in the Rhone valley).

2. The Corrosion of Concrete. A. Nicol. *Silicates Ind.*, v. 17, 1952, pp. 208-213, 252-254.

A review is given discussing the corrosion of concrete.

1951

1. Conservation of Ancient Marble Monuments. A. J. Sofianopoulos.
J. Chem. Education, v. 28, 1951, pp. 79-81.

The chief cause of deterioration of weather-exposed marble is a layer of dust containing clay SiO_2 , soot, and vegetable matter in areas protected from driving rain. This colloidal layer adsorbs SO_2 and oxides of nitrogen to form acids which attack the marble. Deterioration is not caused by oxidation of ferrous iron or from CO_2 in water, as is commonly supposed, because the action is always local. The best means of conservation is periodic washing. Ancient Greek lime mortars in which colloidal organic matter was incorporated have shown outstanding permanence.

1950

1. Bibliographic Summary on the Agents and the Causes of the Corrosion of Concrete. A. Nicol. Rev. Materiaux Construction Taruv. Pub., No. 415, 1950, pp. 111-126 (French).*

The effects of CO_2 , SO_2 , H_2S , bacteria, organic acids, vegetable and animal oils and fats, glycerol, mineral oils, sugar, molasses, beer, ink, and wine on concrete and mortars are reviewed. Means of preserving concrete against corrosive agents and the use of Na silicates, Na_2SiF_6 , phenolic and furan resins, and silcones are also discussed. The use of slag cements, high-alumina cements, fused cements, and pozzolana is recommended.

2. Chemical Corrosion of Concrete and Materials in General. G. Batta.
Chimie & Industrie, v. 63, 1950, pp. 502-511 (French).

A review of the physicochemical phenomena of corrosion by dissolution is given. Disintegration of cement by expansion and the action of sulfates are discussed. The NaCl in sea water retards the expanding action of sulfates in portland cement.

1949

1. Aggressive Action of Waters on Portland-Cement Concrete.
E. D. Rozhdestvenski. Gidrotekh. Stroitel, v. 18, No. 4, 1949,
pp. 17-20 (Russian).

Concrete is attacked by water even in the absence of dissolved CO_2 . Soluble sulfates are harmful through precipitation of CaSO_4 . Analyses of

partly loosened concrete showed increased contents of MgO , SO_3 , and chloride. Accumulation of CaSO_4 to the extent of 9 percent lowers its strength distinctly; with 13 percent CaSO_4 , the concrete loses its strength completely. Microscopic examination of such concrete showed complete absence of spherulites of calcium sulfoaluminate, only CaSO_4 . Chlorides attack concrete both through exchange reactions and through formation of compounds of the type $3\text{CaO} \cdot \text{Al}_2\text{O}_3 \cdot 2\text{CaCl}_2 \cdot 10\text{H}_2\text{O}$ or $3\text{Ca}(\text{OH})_2 \cdot \text{CaCl}_2 \cdot 13\text{H}_2\text{O}$.

2. Weathering of Concrete. Causes of Efflorescence. E. Propst. Bethonstein-Zrg, 1949, pp. 81-82, 102-103 (German).

The various kinds of concrete efflorescences and their many causes are discussed. Water present as a constituent of the cement or mortar, in any paint coat, or simply as free external water may dissolve the solution constituents of the concrete and even part of the difficulty soluble constituents and thus cause weathering. The most troublesome constituents are the sulfates; sulfides are also subject to the action of atmospheric moisture. If the concrete is not sufficiently tight such action may penetrate into the interior, with new compounds being formed from the solutions of old ones. In slowly setting concretes, newly formed Ca sulfoaluminates may appear simply as efflorescence on the surface but may cause rupture of the interior structure. The possible origin of sulfates in various admixtures used in concrete, such as slags, ashes, or crushed brick, is discussed. Less troublesome efflorescence may be due to lime set free from the cement as hydrate, to Cl compounds from soil water, sea water, sea sand, etc., to Fe and Mn, etc. Paints to be used on concrete should be carefully chosen. The presence of gypsum, spar, chalk, etc., in the paint may cause efflorescence.

1948

1. Role of Sulfur Bacteria in the Disintegration of Building Stone. J. Pochon and Y. Tchan. Comp. Rend., Acad. Sci., Inst. de France, v. 226, 1948, pp. 2188-2189. (French).

Bacteria present in damaged stone are shown to be capable of oxidizing hydrogen sulfide to sulfurous and sulfuric acid.

1946

1. Role of Microorganisms in the Alteration (called stone disease) of Paris Monuments. J. Pochon and Y. Tchan. Compt. Rend., Acad. Sci., Inst. de France, v. 223, 1946, pp. 695-696.

Decayed stone from the cathedral of Notre Dame de Paris was found to contain bacteria that convert H_2S to sulfate. It is suggested that these play a role in the decay of the stone, utilizing sulfur from iron sulfide in the stone, or from atmospheric H_2S .

1945

1. Study of the Stones of Brussels' Monuments; Effects of Air Pollution.
C. Carmerman. Soc. Belge. Geol. Paleontol. et d'Hydrol., Bull., v. 54,
1945, pp. 133-139 (French).

A series of case studies showing differential weathering of a variety of stone types in both urban, rural, and coastal environments are cited.

1940

1. Physical, Mineralogical, and Durability Studies on the Building and Monumental Granites of the United States. D. W. Kessler, H. Insley, and W. H. Sligh. Journal of Research of the National Bureau of Standards, v. 25, 1940, pp. 161-206.

Tests on 116 samples of granite (including the "black granites") from the principal producing districts of the United States gave values for various physical properties. In compression, granite is indicated to be stronger than other types of masonry materials except for some quartzites, whereas slate and some of the serpentines are stronger than granite in flexure. The porosity of granite is of the same order as that of the marbles, slates, and quartzites, but much lower than that of most other masonry materials. Although granite ranks as a heavy masonry material, the unit weight of a normal granite is somewhat less than that of marble, slate, and serpentine.

Inspections of granite structures have shown several cases in which the granite scaled to a depth of a few hundredths of an inch over a portion of the surface. Chemical and microscopic studies showed that calcium sulfate was present in the decayed granite but not in newly quarried granite. Experiments were made to determine if calcium sulfate, leached into the granite from external sources or formed in the granite by the action of sulfuric acid on calcite ingredients, would produce scaling. Leaching with a 10-percent solution of sulfuric acid caused some granites to disintegrate within 30 days, but leaching with a saturated solution of calcium sulfate produced no decay in 3 years. It was concluded that the conversion of calcite ingredients to calcium sulfate by sulfuric acid is the probable cause of scaling.

2. Tests of 106 Commercial Cements for Sulfate Resistance. D. G. Miller and P. W. Manson. Proceedings, American Society for Testing and Materials, v. 40, 1940, pp. 988-1001.

Results of 5-yr sulfate resistance tests of 5724 concrete cylinders, 2 by 4 in, made of 106 commercial cements from 74 mills are recorded in this report. Some of the cylinders were continuously stored in the laboratory in 1 percent solutions of magnesium sulfate (MgSO_4), some in 1 percent solutions of sodium sulfate (Na_2SO_4), and some in the water of Medicine Lake, S. Dak. During the 5-yr period, the water of this lake averaged 12 percent total salts, of which two-thirds were magnesium sulfate and one-fourth sodium sulfate. Resistance of the specimens stored

in the laboratory solutions was determined by length changes while resistance of the Medicine Lake cylinders was determined by strength ratios calculated from compression tests at 1 and 5 yr of the Medicine Lake cylinders and cylinders stored in tap water in the laboratory.

The many test and chemical analyses indicate close correlation between sulfate resistance of the cements and the percentage of the compound tricalcium-aluminate.

1939

1. Effect of Sulfur Compounds in the Air on various Materials. L. R. Burdick and J. F. Barkley. U. S. Bureau of Mines, I.C. 7064, April 1939, 9 pp. (Fe39-1)

1937

1. Limestones, Their Origins, Distribution, and Uses. F. J. North. The Weathering of Building Stones, Thomas Murby and Co., London, 1937, pp. 375-380.

Agencies tending to the destruction of limestone, including the role of rain washing, frost action, lichens and mosses, and ammonia, chlorides, and sulfates in the atmosphere are discussed.

1934

1. The Decay of Building Stones through Soot. R. Warnes. Sands, Clays and Minerals, v. 2, 1934, pp. 17-18.

A typical specimen of soot contains 0.25-5.0% free sulfuric acid, 2.8% ammonium sulfate, and 4.6% ammonium chloride. All of these are aggressive agents of decay; the physical properties of soot promote the decay by the tenacity with which water is held in the deposit.

2. The Stone Industries. O. Bowles. Deterioration of Stone, McGraw-Hill New York, N.Y., 1934. pp. 348-360.

Agents of stone deterioration are discussed including: chemical weathering by dissolved SO_2 , CO_2 and ammonium salts; alteration and replacement of minerals; weathering by thermal expansion, frost action, abrasion, and settlements; deterioration due to plant growth and marine borers; and faults in accessory materials and workmanship.

1932

1. Deterioration of Stone Structures, Causes and Prevention. A. Kieslinger.
Published by Franz Denticke, Leipzig and Wein, 1932, 346 pp.,
(German).

The battle against weathering is almost always primarily a battle against moisture, which is the agent of all weathering phenomena. We have also shown that smoke gases (at least with respect to our Austrian stones) have no specific effect, but they accelerate and even multiply the usual weathering phenomena in quite characteristic ways. Thanks to the advances of modern heating techniques, we no longer have to consider this tremendous enemy of our buildings and monuments as irresistible; rather, its effects can be extensively limited, though only if these efforts are supported by the full weight of the authorities, as is, for example, typical of the situation in Vienna. This combatting of immediate sources represents an ideal which can often only be approached. However, the consequences of the action of smoke also can be markedly diminished through appropriate care of the endangered structures. Coatings of dirt are not only ugly, they are also harmful. The surface crusts of the stone monuments and structures studied by Kieslinger are stated to be composed of calcium carbonate in the form of small concretions called "sinter" or "drip stones."

2. Physical Properties and Weathering Characteristics of Slate.
D. W. Kessler and W. H. Sligh. Journal of Research of the National
Bureau of Standards, v. 9, 1932, pp. 378-411.

The examination of 343 samples of slate shingles which had been in service for periods varying from 12 to 130 years indicated that slate deteriorates mainly from a combination of chemical and physical causes. Slates containing both pyrite and calcite in appreciable amounts are subject to decay due to the conversion of a part of the calcite to gypsum. The increase in molecular volume causes scaling of the surface. Slate shingles exposed on the roof decay more rapidly on the downward surface, which is probably due to the leaching and concentration of gypsum. A similar type of decay can be produced by alternately soaking and drying the slate. The slates which are more subject to this type of weathering can be disintegrated by 40 or 50 cycles of this treatment.

Frost may cause deterioration, but the rate of this action is very slow. Aside from chipping off the scales near the edges already loosened in the trimming process, frost plays a very minor part in slate weathering. However, the freezing of water between shingles which are nailed down tightly may cause breakage.

3. The Weathering of Natural Building Stones. R. J. Schaffer. Building
Research Establishment Special Report No. 18, published by His Majesty's
Stationery Office, London, 1932, 139 pp. (Reprinted in 1972)

This report contains sections on: classification of natural building stones; classification of the causes of weathering; atmospheric pollution in relation to weathering; chemical phenomena associated with weathering

(action of acid gases as CO, SO₂); physical phenomena associated with weathering; soluble salts as agents of decay; living organisms as agents of decay; preventive and remedial measures.

1931

1. Notes on the Weathering of Natural Building Stones. G. F. Loughlin. Symposium on the Weathering of Masonry Materials, Proc. ASTM 3, II, American Society for Testing and Materials, 1931, pp. 759-767.

Rather than present a thorough outline on the weathering of building stone certain factors of critical importance are discussed. The majority of these factors are important only as affecting superficial details rather than as affecting the ultimate durability of stone in structures of different kinds, but superficial details are likely to attract the most attention and therefore to assume great importance in the selection of stone.

The weathering of stone depends primarily upon its mineral composition, texture, and structure, and secondarily on the conditions under which it is used. Some minerals are very stable under all ordinary conditions of use, but others are very unstable and a small percentage of them in a stone may be sufficient to affect seriously both superficial detail and even ultimate durability; again a stone may consist entirely of stable minerals but its cohesive strength may have been originally low or it may have been seriously decreased by microscopic fracturing of natural or artificial origin.

2. The Weathering of Slate. C. H. Behre, Jr. Proc. Amer. Soc. Testing Materials (preprint), v. 66, 1931, pp. 37-43.

The oldest roofing slate in America has been exposed 190 yrs. and the buildings on which it was successively placed have been torn down twice. Spalling due to alternate heating and cooling is known to occur very rarely. Slates are highly resistant to frost action and generally to chemical action, although chemical decay of some slates takes place. Those with lowest resistance contain Ca, Mg or Fe carbonates, or their isomorphous mixtures. Practically all slates lose part of their luster upon prolonged exposure.

3. Weathering of Aggregates. L. O. Hanson. Proc. Amer. Soc. Testing Materials (preprint), v. 66, 1931, pp. 44-57.

Accelerated weathering tests of 5 cycles caused disintegration roughly comparable with that of Wisconsin limestones. A very severe accelerated weathering test caused a weakening of 18 mortar mixes inversely proportional to their 28-day strengths. Cross-bending tests are the most satisfactory criteria of the destructive effects of weathering tests on mortars.

1929

1. Contributions to the Study of Fluorescence. W. A. McIntyre and R. J. Schaffer. Transactions of the British Ceramic Society, v. 28, 1928-1929, pp. 363-380.

The nature and sources of salts found on the surface of brick work, terra cotta, and stone are discussed. It is contended that crystallization pressure of soluble salts within pores is the most important factor in the decay process. Sulfates from neighboring materials can cause similar decay in non-calcareous materials, such as siliceous sandstones.

2. Factors Governing the Durability of Clay Building Materials. W. A. McIntyre. Transactions of the British Ceramic Society, v. 28, 1928-1929, pp. 101-123.

Biological, physical, and chemical factors affecting the durability of brick, roofing tiles, and structural terra cotta are discussed. The results of accelerated weathering tests performed by the Building Research Station on wet specimens with a mixture of 5% CO_2 and S are reviewed. One of the main factors in the weathering of clay building materials is the texture of the original material. Crystallization of soluble salts, especially alkali sulfates in the body of the material is cited as the major cause of decay. Sodium sulfates tend to be more prevalent in efflorescence than potassium sulfates despite a dominance of K_2O over Na_2O in the original material. Calcium sulfates are surprisingly absent from the efflorescences tested. Sources of salts are discussed: soil, mortar, original material, atmospheric gases. Results indicate no direct relation between clay composition and attack by atmospheric gases, except for a rough proportionality between calcium content and gas action. Field observations indicate that differential weathering is related to exposure to rain wash. Absence of alkali salts on roofing tiles is attributed to rain wash preventing crystallization of these salts.

1926

1. Building Stones, Their Properties, Decay, and Preservation. A. R. Warnes. Published by Ernest Benn Limited, London, 1926, 260 pp.

In the opinion of the author, the action of bacteria in causing decay of stone is doubtful, and even if it does occur in isolated cases, the amount of decay produced by the nitric acid formed is very little when compared with that caused by deleterious substances in the atmosphere and in rainwater. The mechanisms of attack on stone by SO_4 , CO_2 , NH_4 , Cl, and $(\text{NH}_4)_2\text{SO}_4$ is discussed. The discussion of weathering agents include wind, diurnal temperature variation, clay content, cleavage planes, and the variety of soluble salts in commonly used mortars.

1925

1. Some Aspects of Stone Decay. J. J. Fox and T. W. Harrison. Soc. Chem. Ind., v. 44, 1925, pp. 145T-149T.

Seeing that water is the chief agent and vehicle of corrosive substances as well as the weathering agent, it might prove the most desirable course in the long run to get the stone into as dry a condition as possible and then render it impermeable so that neither water nor gases could gain admittance. We conclude that the most serious agent of stone decay in towns, apart from natural weathering, mechanical defects, and faulty stone, is atmospheric sulfurous or sulfuric acid; bacterial action, if it is found to occur generally, may be of importance, but our information on this part of the subject does not convince us that it is usually a serious factor. The selection of a universal stone preservative is difficult, if not impossible, and the best hitherto suggested still need investigation on a large scale and in conditions as natural as possible.

2. Stone Decay and the Preservation of Buildings. A. P. Laurie. J. Soc. Chem. Ind., v. 44, 1925, pp. 86T-92T.

Investigations of the deterioration of Lincoln Cathedral, Elgin Cathedral, Durham Cathedral, and Ely Cathedral, including analysis of surface incrustations, particularly the depth of penetration of sulfates into the stone are discussed. The author considers rain to be a deliverer of SO_2 and a remover of CaSO_4 prior to the harmful effects of its hydration.

1917

1. Building Stones and Clays. C. H. Richardson. Chapter 2 in Physical Properties and Weathering of Building Stones, published by C. H. Richardson, Syracuse, New York, 1917, pp. 15-37.

The phenomena of mineral solution and hydration by agents dissolved in rain water, CO_2 , SO_2 , HNO_3 , HCl , and NH_4 are discussed. The effect of NaCl in sea air increases the solvent action of H_2O and the effect of deposited smoke in attracting other depositions. A study of pure rain dissolving Solentist limestone at a rate of .85 mm per century is cited.

1914

1. Big-City Patina. O. W. Fischer. Weiner Bauindustrie Zeitung, v. 31, No. 24, 1914, pp. 151-153 (German).

Marble sculpture is more susceptible to the disfiguring effect of soot and dirt, when the size of the crystallites composing the stone is finer. In the case of fine-grained marble, the dirt works its way below the surface, after which cleaning no longer serves to restore the appearance. Regular, frequent washing is the only means of preserving the surface of such sculpture.

1910

1. The Weathering of Our Large Monuments. V. Manikonsky. Die Denkmalpflege, v. 12, No. 7, 1910, pp. 51-54 (German).

According to Building Supervisor Frische in Lowen, examination of monuments that have suffered decay shows that the areas of limestone where decay is absent or slight are rich in silica, whereas the severely weathered areas contain only traces of silica. Hence it follows that defects in the chemical composition of the stone, particularly the lack of silica, is as often the source of decay as is the effect of chemical agents in the atmosphere.

According to the geologist Delesse, the decay of the stone of Westminster Palace, London, is due to its content of magnesia, which reacts with the sulfur and ammonia in the air, producing salts that destroy the stone. In the past, every attempt at preservation has failed, and the only effective means of obtaining a durable structure has been the selection of a good stone in the beginning.

Louis Guicciardini (1567) has said in his description of the Lowen town hall (1448-1459): "Unfortunately this easily worked stone has the defect of being porous and of exfoliating when imbibed water freezes in it, and it does not harden in the air as other stones do. For this reason, the policy was adopted of painting it with oil." This practice was observed until its first restoration in 1829, and it is probable that the sculpture and the finely detailed ornamentation of the 15th century survived only because of this precautionary measure. Indeed, it can be shown through other examples that mere whitewashing of stones with slaked lime has a preservative effect. Most stones, granites, sandstones, and limestones carry a greater or lesser number of the seeds of deterioration within themselves, of which the worst are the salts that develop in the interior and on the surface due to the effects of the atmosphere, acids, dampness, and nitrogenous matter in the soil. The artisans of the Middle Ages, knowing that even the densest stone tends to take up some water, oiled the stones, and took the most painstaking measures to insure their dryness. Perhaps it was for this reason that the stone of the Cologne Cathedral has lasted for seven centuries.

1908

1. The Testing of Natural Building Stones and Their Resistance to Weather. J. Hirschwald. Published by Wilhelm Ernst and Sohn Verlag, Berlin, 1908, 675 pp.

Extensive tabulations of the properties and weathering characteristics of the stone present in many monuments and historic buildings in Germany and neighboring regions are contained.

The weathering of limestones stems, in general, from the following factors: a) defective crystal growth resulting from discontinuous crystal formation, pelitomorphic constitution of the calcium carbonate, or presence of foreign substances, particularly argillaceous, bituminous or carbonaceous inclusions; b) the effect of frost; c) substantial content of iron bisulfide.

The weathering of those limestones which are not affected by frost is principally due to the gradual loosening of the binding of the crystallites resulting from the solvent effect of carbonic acid-containing water. This is shown by the fact that dense, microcrystalline limestones, which show no trace of penetration of a dye solution into fresh surfaces.

1903

1. Stones for Building and Decoration. G. P. Merrill. The Weathering of Building Stone, John Wiley and Sons, London, 1903, pp. 418-446.

Physical and chemical agencies of building stone deterioration are discussed, including: heat and cold, friction, growing organisms, composition of the atmosphere and the resultant processes of oxidation, deoxidation, solution; induration of stone on exposure; and weathering properties of various classes of stone.

1883

1. The Decay of Building Stones of New York City. A. A. Julien. Transactions of the New York Academy of Science, 1883, pp. 67-78, 120-138.

This report was also published as part of the 1880 census (MSC 1880-2).

1880

1. Rock Weathering as Illustrated in Edinburgh Church Yards. A. Geikie. Proc. Royal Soc., Edinburgh, 1879/1880, pp. 518-532.

Observations on the weathering of limestone, granite, marble and sandstone grave markers in a "large town, with a moist climate and plenty

of coal smoke" are recorded. The weathering rate of marble was computed to be 9 mm/century and that of granite to be 0.85 mm/century.

2. The Durability of Building Stones in New York City and Vicinity.
A. A. Julien. Chapt. 8 in Building Stones and the Quarry Industry,
U.S. Tenth Census, v. 10, 1880, pp. 364-384.

From the commercial relations of New York to the quarries of this country and of foreign countries, and from the enormous amount of construction on which the practical value of building materials is tested in that city, this chapter, though local in title, forms the best availability summary upon the durability of building stone for the United States.

ELASTOMERS

1980

1. A Review of Air Pollutant Damage to Materials. J. E. Yocum and A. R. Stankunas. Draft Report to Environmental Criteria and Assessment Office, Office of Research and Development, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, December 1980, 92 pp. (Fe80-2)
2. Collector Sealants and Breathing. M. A. Mendelsohn, R. M. Luck, F. A. Yeoman, and F. W. Navish, Jr. Westinghouse Electric Corp., Pittsburgh, PA (USA), Research and Development Center, NTIS PC A09/MF-A01 February 1980, 278 pp.

The objectives of this program were: (1) to investigate the pertinent properties of a variety of possible sealants for solar collectors and identify the most promising candidates, and (2) to study the effect of breathing in flat-plate, thermal solar collector units. The study involved two types of sealants, class PS which includes preformed seals or gaskets, and Class SC which includes sealing compounds or caulks. It was the intent of the study to obtain data regarding initial properties of candidate elastomers from manufacturers and from the technical literature and to use those sources to provide data pertaining to endurance of these materials under environmental service conditions. Where necessary, these data were augmented by experimental measurements. Environmental stresses evaluated by these measurements included elevated temperatures, moisture, ultraviolet light, ozone and oxygen, and fungus.

The second major area of the work involved a study of the effects of materials and design on the durability of solar collectors. Factors such as design, fabrication, materials of construction, seals and sealing techniques, and absorber plate coatings were observed on actual field units removed from service. Such phenomena as leakage, corrosion, and the formation of deposits on glazing and the absorber plate were noted. An evaluation of the properties of several desiccants was made in order to provide means to mitigate the deleterious effects of water on collector life. Adsorbents for organic degradation products of sealants were also investigated in order to protect the glazing and absorber plate from deposited coatings. Since adsorbents and desiccants in general tend to take up both water and organic decomposition products, relative affinities of a number of these agents for water and for organic compounds were determined. Results are presented in detail.

3. Critical Review of the Available Physico-Chemical Material Damage Functions of Air Pollution. M. Benarie. Report EUR-6643, Commission on the European Communities, 1980, 97 pp. (Fe80-8)

1979

1. Degradation of Adhesion of Coated Tire Cords to Rubber by Atmospheric Pollutants. R. E. Hartz and H. T. Adams. Tire Performance and Reinforcement, American Society for Testing and Materials, ASTM STP 694, 1979, pp. 139-152.

The effects were studied of nitrogen oxides, SO_2 , ultraviolet light, O_3 and air on adhesion of glass-coated steel cords and of resorcinol-HCHO-latex (RFL) adhesive-coated nylon 66, polyester, and rayon tire cords to rubber compounds. RFL-dipped nylon and polyester tire cords lost adhesion to rubber stocks on exposure to O_3 and O_3 -ultraviolet light; other degradants, such as NO , NO_2 , SO_2 , heat, and air, had less effect on adhesion loss. Adhesion degradation was caused by attack on double bonds of the butadiene component of the rubber latex and subsequent reduction of sites for cure with rubber formulations. Addition of N, N-ethylenebis (stearamide) wax to the RFL dip provided protection from adhesion loss during exposure (by blooming) to the surface of the dip on the cord. Brass-coated steel rapidly lost adhesion on exposure to NO_2 and SO_2 ; humidity and heat did not effect adhesion loss. Corrosion of metals by acidic pollutants eliminated sites for cure to sulfur adducts of adhesion stocks.

2. Glovebox Deterioration in the Hanford Engineering Development Laboratory Fuel Fabrication Facility. W. O. Greenhalgh, R. C. Smith, and D. L. Powell. NTIS Report PC-A03/MF-A01, July 1979, 44 pp.

Neoprene glovebox gloves have been found susceptible to periodic rapid deterioration under normal operating conditions in fuel fabrication facilities. Examinations of glove failure histories and measurements of the atmospheres in inert atmosphere dry-boxes indicated ozone at low concentrations of 100 to 500 ppb was probably the most important factor in rapid glove deterioration. Testing of a variety of new glove deterioration. Testing of a variety of new glove materials indicated that hypalon and ethylene-propylene-diamine monomer (EDPM) gloves have greater than 30 times the longevity of neoprene in low-level ozone concentration atmospheres. Comparative tests over a 30-month period have also confirmed that the two glove candidates have a significantly longer operating life.

1978

1. The Effect of the Polluted Urban Atmosphere on Degradation of Polymers. F. Flajsman. Chem., Kunstst.-Aktuell (1977), 1978, pp. 21-23.

Pronounced oxidative degradation of SBR and isoprene rubber was observed when exposed to various degrees of air pollution in an urban environment. No changes in polymer structure were observed where pollution was absent. Mechanisms of oxidation of the unsaturated polymers were discussed.

1977

1. Effects of Sulphur Dioxide on Materials. S. K. Gajendragadkar. Chem. Age India, v. 28, No. 8, 1977, pp. 673-677 (Fe77-5)
2. Effects on Economic Materials and Structures. J. E. Yocom and J. B. Upham. Chapter 2 in Air Pollution, edited by A. C. Stern, Academic Press, New York, N.Y., v. 2, 1977, pp. 65-116. (Fe77-6)
3. Estimation of Pollutants Concentration in Atmosphere by Measuring Corrosion Rates of Several Metals. II. Correlation Between Reflectances of Exposed Metals and Deterioration of Exposed Rubber. G. Takao and M. Masakasu. Taiki Osen Kenkyu, v. 11, No. 6, 1977, pp. 452-455 (Japanese). (Cu77-2)

1976

1. Air Pollution and Aspects of Polymer Degradation. I. Cook. ICCM Bulletin, v. 2, No. 4, December 1976, pp. 4-20.

Air pollution and its effects on the chemical structure of polymer materials is discussed. Pollutants are first defined and the general characteristics of air pollution reviewed. Then the author covers the effects of the sulfur compounds, especially sulfur dioxide, ozone, and nitrogen dioxide on paper, textiles, and other polymer materials.

2. Effects of Gaseous Pollutants on Materials: A Chamber Study. F. H. Haynie, J. W. Spence, and J. B. Upham. NTIS Report PB-251580, 1976, 98 pp. (Fe76-5)
3. Effects of Power Plant Emissions on Materials. J. E. Yocom and N. Grappone. Research Corporation of New England, Wethersfield, Connecticut, NTIS Report PB-257539, July 1976, 85 pp. (Fe76-6)
4. Material Changes by Ozone. U. Arndt and H. Ross. VDI-Ber., v. 270, 1976, pp. 197-210 (German). (OM76-11)
5. Physical and Economic Damage Functions for Air Pollutants by Receptors. B. Lui and E. S. Yu. Report No. EPA-600/5-76-011, Environmental Protection Agency, September 1976, 172 pp. (Fe76-13)
6. Protection Against Atmospheric Corrosion. K. Barton. Translated by J. R. Duncan, Wiley, New York, N.Y., 1976, 194 pp. (Fe76-14)

1975

1. Environmental Exposure System for Studying Air Pollution Damage to Materials. J. W. Spence, F. D. Stump, F. H. Haynie, and J. B. Upham. NTIS Report PB-240615/5ST, 1975, 46 pp. (Fe75-11)
2. Sulfur Dioxide and Material Damage. D. G. Gillette. J. Air Pollution Control Association, v. 25, No. 12, December 1975, pp. 1238-1243. (Fe75-17)

1974

1. Design of a Laboratory Experiment to Identify the Effects of Environmental Pollutants on Materials. J. W. Spence and F. H. Haynie. Corrosion in Natural Environments, American Society for Testing and Materials, ASTM STP 558, 1974, pp. 279-291. (Fe74-10)
2. Effect of Air Pollution on Materials and Technical Equipment. D. Knotkova, K. Barton, and B. Dolezel. Ochr. Ovzduš., v. 6, No. 6, June 1974, pp. 75-83 (Czech). (Fe74-12)
3. Effect of Oxidative Components of Air Pollutants on the Degradation of Polymers. F. Flajsman. Kem. Ind., v. 23, No. 2, 1974, pp. 96-100 (Croatian).*

The effects of NO₂ and SO₂ on polyethylene, polypropylene, polystyrene, poly(methyl methacrylate), PVC, polyacrylonitrile, nylon 66, butyl rubber, polyisoprene, and polybutadiene were examined. Films approximately 20 μm thick were cast from solutions and exposed to NO₂ at 35° C and SO₂ at 25° C and mixtures of these gases with O₂ and air, with or without U.V. irradiation. Changes in limiting viscosity and I.R. spectra were determined.

4. How Rubbers Compare in Weathering Resistance. J. A. Vaccari. Mater. Eng., v. 79, No. 4, April 1974, pp. 58-59.*

Weathering degrades all rubbers, but some rubbers are much more resistant than others to atmospheric attack. Oxygen, ozone and ultraviolet irradiation are some of the major causes for the weathering of rubbers. Antioxidants are primarily of two types: (1) those which cause staining such as phenyl-beta-naphthylamine (PBNA) and (2) those which are nonstaining such as phenolics and alkylated phenol phosphite. Ozone attack has become a problem of considerable concern in high smog areas. Use of an ozone resistant rubber such as butyl, chloroprene, ethylene-propylenediene, chlorosulfonated polyethylene, epichlorohydrin, polyarylate, fluorocarbon and silicone is an obvious solution. However, the ozone resistance of natural rubber, butadiene and styrene-butadiene can be improved chemically by compounding with protective additives

(antiozonants) such as phenylene-diamines and other compounds. Similarly, photochemical degradation of rubbers from ultraviolet rays in sunlight can be reduced by protective additives which screen out the harmful energy. In general, saturated rubbers such as chlorosulfonated polyethylene, ethylene-propylene, fluorocarbon and silicone are more resistant to UV degradation than natural rubber and styrene-butadiene. Few if any rubbers meet the "outstanding" weathering resistance of silicone rubber. Ethylene-propylene-diene is noted for its overall weathering resistance, including color stability.

5. The Economic Damages of Air Pollution. T. E. Waddell. NTIS Report PB-235701, 1974, 156 pp. (Fe74-21)
6. The Economics of Clean Air In Perspective. F. H. Haynie. Materials Performance, v. 13, no. 4, April 1974, pp. 33-38. (Fe74-22)

1973

1. Concentrations, Decay Rates, and Removal of Ozone and Their Relation to Establishing Clean Indoor Air. R. H. Sabersky, D. A. Sinema, and F. H. Shair. Environ. Sci. Technol., v. 7, No. 4, 1973, pp. 347-353. (OM73-2)

1971

1. Present Status and Prospects on Air Pollution. U. Bardelli. Ingegneria, v. 5, 1971, pp. 311-316 (Italian). (Fe71-19)

1970

1. Effects of Ozone on Deterioration of Rubbers (Blooming Theory). T. S. Huh. Kongyon Rebyu, v. 12, No. 3, 1970, pp. 7-9 (Korean).

Ozone deterioration of rubbers is reviewed.
2. Interstate Surveillance Network--1969 Data. Division of Air Quality and Emission Data, Report NAPCA/APTD 70-3, U.S. Department of Health, Education and Welfare, May 1970, 203 pp. (OM70-5)
3. Systems Analysis of the Effects of Air Pollution on Materials. R. L. Salmon. NTIS Report PB-209192, January 15, 1970, 196 pp. (Fe70-13)

1969

1. Combined Effects of Deformation and Ozone on Molecular Bond Rupture in Rubber. L. K. De Vries, E. R. Simonson, and M. L. Williams. Polym. Prepr., Amer. Chem. Soc., Div. Polym. Chem., v. 10, No. 2, 1969, pp. 1190-1197.

Electron paramagnetic resonance spectra of ozone-treated and deformed rubbers showed that the free radical formation threshold occurs below visible cracking, the bond rupture rate increases monotonically with strain above the strain threshold, and bond scission increases linearly with ozone concentration. EPR spectra of nylon 66, polyethylene, and polypropylene at various temperatures showed that the number of bonds broken is independent of temperature below the glass-transition temperature, above which the number drops off rapidly. In the rubbers no bond rupture occurred below the strain threshold.

2. Minimum Paint Film Thickness for Economical Protection of Hot-Rolled Steel Against Corrosion. J. D. Keane, W. Wettach, and W. Bosch. J. Paint Technol., v. 41, No. 533, 1969, pp. 372-382. (Fe69-33)

1967

1. Corrosion by Air Pollution. J. R. Goss. Proc. Annu. Conf., Nat. Soc. Clean Air, No. 34, 1967, pp. 75-92. (Fe67-4)
2. Fundamental Degradation Processes Relevant to Outdoor Exposure of Polymers. H. H. G. Jellinek. Applied Polymer Symposia, No. 4, 1967, pp. 41-59.

A survey is presented of fundamental reactions which can take place when polymers are exposed, separately, to light and oxygen. The kinetics of chain scissioning and crosslinking is presented in some detail. Oxidation is discussed on basis on Bolland's mechanism. A number of examples to illustrate discussion are given. The simultaneous effect of light and oxygen is illustrated by considering poly(ethyl acrylate). The effect of ozone and air pollutants is briefly discussed.

3. The Effects of Photochemical Oxidants on Materials. L. S. Jaffe. J. Air Pollution Control Assoc., v. 17, No. 6, 1967, pp. 375-378.

The excessive cracking of rubber products is one of the earliest indications of the presence of atmospheric photochemical oxidants. Excessive cracking is caused by atmospheric ozone formed in the photochemical smog formation process. Ozone effects on textiles, dyes and other materials are also addressed.

1966

1. Ozone Aging of Rubber. Y. S. Zuev. Zh. Vsev. Khim. Obschesta im. D. I. Mendeleeva, v. 11, No. 3, 1966, pp. 288-293 (Russian).

The nature of attack by ozone on rubber products, effects of environment and methods of its prevention, including amines used as antiozone agents, is discussed.

1963

1. Mechanism of Ozone Cracking of Rubber. P. Y. Inagaki, T. Shiga, and T. Arai. Nippon Gomu Kyokaishi, v. 36, 1963, pp. 613-619 (Japanese).

The relation between theoretical considerations of the mechanism of O_3 cracking of rubber surfaces and experimental results is discussed. The surface changes of unstrained and strained rubber exposed to ozonized air are observed by the electron microscope. The process in which the surface of unstrained rubber becomes covered with a stable oxidized film and also the process in which ozone cracks grow on the surface of strained rubber are discussed. Visual inspection revealed that migration to the antiozonants between rubber surfaces is related to O_3 resistance. To explain the variation of the shapes of O_3 cracks, the theory proposed in the previous report is sufficiently valid if the concept of stress relaxation of rubber surfaces is introduced. Results such as the relation between elongation ratio and the time until cracks occurred, the effects of softeners, and the effects of concentration of O_3 and antiozonants agree with theoretical considerations.

1962

1. Physical and Chemical Mechanisms of the Deterioration of Rubbers Under the Action of Ozone. D. Jaroszynska. Polimery, v. 7, No. 11, 1962, pp. 406-410 (Polish).

Chemical reactions of atmospheric ozone with rubbers containing double bonds, rearrangements of the ozonides formed, and the mechanism of ozone cracking of rubber, as well as the factors influencing the cracking-rate, are discussed.

1958

1. Accelerated Ozone Aging. W. L. Dunkel, and R. R. Phelan. Rubber Age, v. 83, No. 2, May 1958, pp. 281-286.

The investigation of the ozone concentration range of 25 pphm to 0.8 vol-pct to obtain an accelerated ozone test which could predict, fairly accurately, weathering performance of one polymer compared to another is

reported. Compounding variables affecting ozone resistance of butyl rubber vulcanizates were determined. These included cure state, degree of unsaturation in polymer, filler loading, plasticizer content, and contamination.

2. Ozone Resistance of Butyl Rubber. R. F. Grossman and A. C. Bluestein. Rubber Age, v. 84, No. 3, December 1958, pp. 440-448.

The mechanism of ozone attack on butyl rubber vulcanizates was studied. Ozone failure time is shown to be dependent upon applied stress only when reorientation of polymer chains is possible. Second order dependence upon ozone concentration in cracking indicates a more complicated process than simple ozonolysis of double bonds. A mechanism of simultaneous ozonolysis and oxidation is proposed. Ozone attack before visible cracking is shown to be a surface process.

1956

1. Aging Accelerated by Ozone and a Testing Apparatus. C. Thelamon. Rev. Gen. Caoutchouc, v. 33, 1956, pp. 247-252 (French).

A simple apparatus is described and illustrated in which test specimens are exposed under stress to air containing a known concentration of O_3 . The apparatus is constructed only of materials which are impervious to attack by O_3 . Most tests with this apparatus were made with an O_3 concentration of 2.7 cc/m^3 of air, which gives reproducible results. Deterioration is judged by comparing the resulting cracks with a series of photographs of standard samples. After a simple series of tests of several elastomers, the protection of natural rubber (I) was studied in more detail. Photomicrographs show the cracking of (I), GR-S(II), "cold" butadiene-styrene copolymer (III), butadiene-acrylonitrile copolymer (IV), Neoprene (V). Butyl rubber (VI), Hypalon (VII), and Silicone rubber (VIII) also were tested. Cracks appeared first on (III), then on (I) and (II), and finally on (IV). No cracks appeared on (V), (VI), (VII), or (VIII) during 24 hours. Parallel results were obtained by outdoor exposure. With (I), physical methods of protection are ineffective when samples are under stress. Among protective agents, Ni dibutyldithiocarbamate is effective against cracking but makes vulcanizates poorer in heat aging. Favorable results are obtained by the joint effects of a protective wax and an O_3 inhibitor, and by the addition of (V) or (VII), but not of (VI), to (I).

2. Ozone Cracking of Natural and Synthetic Rubbers. J. E. Gaughan. Rubber World, v. 133, 1956, pp. 803-808.

Recent developments and present knowledge of the subject are reviewed.

1955

1. Corrosion Aspects of Air Pollution. L. Greenburg and M. B. Jacobs. Amer. Paint J., v. 39, No. 43, 1955, pp. 64-78. (Fe55-2)

1954

1. Deterioration of Materials - Causes and Preventive Techniques. G. A. Greathouse and C. J. Wessel. Reinhold Publishing, New York, N.Y., 1954, 835 pp. (OM54-1)

1953

1. Cracking of Stressed Rubber by Free Radicals. J. Crabtree and B. S. Biggs. J. Polymer Sci., v. 11, 1953, pp. 280-281.*

A cracking of rubber, indistinguishable from that produced by O_3 , occurs on exposure of stressed rubber to vapors of volatile peroxides and ultra-violet irradiation. The reaction occurs in an atmosphere of nitrogen and apparently results from the action of free radicals liberated from the peroxides. NO_2 accelerates the cracking by catalyzing the peroxide photolysis. Cracking by tert-Bu, Ph, Bz, Ac, and OH radicals is observed.

2. Deterioration of Stretched Rubbers Under the Influence of Ozone. Y. S. Zuev and A. S. Kuz'minskii. Doklady Akad. Nauk S.S.S.R., v. 89, 1953, pp. 325-328.*

The work described examines the mechanism of this cracking after reviewing the mechanisms previously reported in the literature, and disagrees with the activation theory. Necessary fundamental conditions promoting cracking are: (1) presence of reactive sites (double bonds) and (2) presence of a stretching force. Compressive force is shown to be inactive. The chemical reaction of rubbers with O_3 is specific, proceeds by the rupture of the hydrocarbon chains or the surface of the rubber through formation of brittle ozonides, and is characterized by the absence of diffusion of O_3 into the body of the sample. Cracking by O_3 is regarded as a combination of chemical and physical processes.

3. Ozone Cracking--A Cinematographic Study. D. M. Smith and V. E. Gough. Trans. Inst. Rubber Ind., v. 29, 1953, pp. 219-237.*

The cracking of strained rubber exposed to O_3 was followed as a dynamic process by means of time-lapse photomicrography. The rate of crack formation is a normal logarithmic function of time. The pattern of initial cracks is randomly distributed over the sample. The number of cracks is of the order of 1 per 10^9 to 10^{15} double bonds. The initiation of cracking probably involves the simultaneous attack by O_3 of several

adjacent double bonds in different molecules. The rate of crack growth is linear with time except as altered by interference between neighboring cracks.

1952

1. The Ozone Cracking of Rubber. C. H. Leigh-Dugmore. Rubber Age and Synthetics, v. 33, 1952, pp. 398-400.

Experimental observations and explanations of cracking based on physics and on critical elongation are reviewed and discussed.

1951

1. A Study of the Factors Affecting the Weathering of Rubberlike Materials. E. W. Ford and L. V. Cooper. India Rubber World, v. 124, pp. 696-698, and v. 125, pp. 55-60, 1951.*

Recent literature on the weathering of vulcanized rubber and also new laboratory work described in the present paper lead to the conclusion that O_3 is the only agent which alone produces visible weathering effects on vulcanizates of Hevea rubber, GR-S, Neoprene, and Butyl rubber. The other important factors (light, humidity, and heat) influence the rate of attack by O_3 but do not themselves cause visible deterioration. A newly designed weathering apparatus is described and illustrated. Test specimens can be exposed while elongated either statically or dynamically. The O_3 concentration is controllable within the range of 0.05 to 4500 ppm, the temperature from -40° to 100° C, and the relative humidity from 0 to 100 percent at any temperature. A system of lights and filters makes possible coverage of the entire spectrum from 2200 to 800 A, in bands approximately 500 A wide. Control of O_3 is based on continuous titration of iodine liberated from aqueous KI by passage of a constant flow of air containing O_3 . Variation in the condition of the solution controls the operation of the O_3 generator and maintains the concentration at a value governed by the rate of injection of aqueous $Na_2S_2O_3$. The temperature is regulated thermostatically and cooling is by solid CO_2 . The source of light is specially designed with filters. Representative results are given to show the reproducibility of data, the relative weathering of different polymers, and the effects of O_3 , stretching, heat, light, and humidity, individually and in combination. Butyl rubber vulcanizates (unloaded, black, and white) showed extremely high resistance to O_3 . Corresponding Neoprene vulcanizates showed nearly as high resistance, Hevea rubber vulcanizates showed slightly better resistance than did similar GR-S vulcanizates, but both were much inferior to Neoprene vulcanizates. Exposure to light in the absence of O_3 caused little change under the particular conditions. Exposure to light before or concurrently with exposure to O_3 reduced to a small extent the rate of attack by O_3 .

2. Aging of Rubbers and Resins by the Action of Light, Ozone, and Other Factors. Y. S. Zuev. Vsesoyuz. Khim. Obshchestvo im. D. I. Mendeleeva, Vysokomolekul. Soedineniya, No. 11, 1951, pp. 40-50 (Russian).

This review covers the effects of light and oxygen on aging of rubber, the mechanism of the oxygen reaction under the influence of light, the action of O_3 and activators for light on aging, sensitization, inhibitors of aging, and changes of structure on aging.

3. Deterioration of Organic Polymers. B. S. Biggs. Bell System Tech. J, v. 30, 1951, pp. 1078-1101; and Bell Telephone System Tech. Pubs., Monograph No. 1913, 1951, 25 pp.

Organic polymers suffer from exposure (weathering) owing to attack by H_2O , O_2 , and O_3 as principal agents. Water attack may cause failure of the type in which surface effects are pronounced and in which electrical properties deteriorate. The attack of O_3 is most effective where unsaturation exists. Ozonides form which subsequently decompose with a rupture of the molecular chain. Rubber is rapidly attacked by O_3 . Oxygen is involved in reactions which contain free radical mechanisms activated by light. Cleavage of single or double carbon bonds results in smaller molecular aggregates causing a serious loss of physical properties. It is clear, in the case of polymers whose molecular weights are in the thousands, a very small weight percentage of oxygen (relatively large number of oxygen atoms compared to the number of polymer molecules) can cause very drastic effects. Once some free radicals are formed, chain reactions are set up at increasing rates that cause rapid failure; that is why a given amount of antioxidant is much more effective initially than if incorporated after partial degradation. Carbon black is an effective inhibitor of the chain reactions, and in some cases phenylsalicylate is also effective, in that they absorb actinic radiant energy which activate free radical mechanisms.

1950

1. The Influence of Ozone on Paint Vehicles and Some Macromolecular Products. F. J. Hermann, H. W. Talen, and G. J. Scheffer. Central Inst. Materiaal Onderzoek Afdel. Verf, Circ. No. 68, 1950, 25 pp.*

Films of stand oil-phenolic varnish (I), tung oil-phenolic varnish (II), alkyd varnish, nitrocellulose-containing maleicresin, castor oil and $C_4H_4(CO_2Bu)_3$, rubber (III), Neoprene (IV), hydrochlorinated rubber (samples containing 5 percent of the original double bonds) (V), and fully saturated chlorinated rubber, polyethylene, and polyvinyl chloride-acetate were stretched and exposed to O_3 . III, IV, and V developed cracks; the other materials did not. O_3 treatment increased the tensile strength of I and II. The relation among stress, strain, and time were determined for the untreated materials, which were then classified according to their rheological behavior. O_3 caused cracks only in those stretched samples which possessed elastic properties and carbon double bonds.

1946

1. Weathering of Soft Vulcanized Rubber. J. Crabtree and A. R. Kemp. Ind. Eng. Chem., v. 38, 1946, pp. 278-296.*

The investigation is concerned with the weathering of vulcanized rubber, and includes an extensive study of the effects of light, O_2 , and O_3 on vulcanizates of various types under different conditions of strain, temperature, concentration of O_3 , intensity of light, humidity, state of cure, etc. The results confirm previously published work by Newton which shows that 2 important phenomena must be distinguished, viz., cracking caused by O_3 where the samples is strained and surface checking, crazing, or hardening resulting from oxidation induced by light. The most important evidence that cracking is caused by O_3 is that: (1) in its absence, light and air do not crack vulcanized rubber stretched up to 50% elongation; (2) stretched rubber cracks out-of-doors just as rapidly at night as in daytime and just as quickly in shade as when completely exposed; (3) artificially generated O_3 at the same concentration as in atmospheric air has exactly the same cracking effect as does out-door exposure in shade, and (4) no other component of the atmosphere causes cracking at the same rate and of a similar character. Even at concentrations of 1-5%, O_3 has no evident effect on vulcanized rubber which is relaxed, whereas even at 2% elongation, attack by O_3 is rapid. Attack by O_3 induced by light can be retarded best by fillers which impart a high degree of reflectance to the vulcanizate; TiO_2 is the best; carbon black and Fe_2O_3 are very effective. The effects of blooming waxes on cracking by O_3 are discussed. They depend on the type of wax, the temperature the degree of strain, the concentration of wax, other ingredients in the compound etc., and offer a complicated problem. In general, GR-S vulcanizates are less susceptible to oxidation induced by light and more susceptible to attack by O_3 than corresponding natural rubber vulcanizates. Protective waxes have relatively greater effects in GR-S but, as with natural-rubber vulcanizates, they are useless when dynamic flexing is involved. Some results with Butyl, butadiene-acrylonitrile polymer, and Neoprenes are mentioned briefly.

1940

1. Action of Ozone on Rubber. F. J. Norton. The Rubber Age, v. 47, No. 2, 1940, pp. 87-90.

In this investigation the action of ozone on rubber compositions, not exposed to direct light but under tension and compressions, was studied. It was concluded that, in order to specify the life of a rubber composition, the mechanical stress as well as the ozone concentration in the surrounding atmosphere must be known.

2. Action of Ozone on Rubber and Other Materials. F. J. Norton. Gen. Elect. Rev., v. 43, 1940, pp. 93-95.*

Tests were made of the action of O_3 on rubber mixtures mostly ordinary rubber insulating tape (70% rubber by vol.), not exposed to direct light but under tension and compression. The results indicate that the time for rupture to occur depends both on the stress and on the concentration of O_3 . Corona-resisting rubber was the most resistant. Alkyd, phenolic and vinyl resins and cellulose acetate showed no evidence of O_3 attack, either when stressed or not unstressed. During exposure to contrated O_3 (44.5 mg./l.) the temperature of the stressed rubber increased from 32° to 39°. The deterioration of rubber insulation by corona discharge and light is probably related to O_3 formation.

1931

1. The Appearance of Atmospheric Cracks in Stretched Rubber. A. Van Rossem and H. W. Talen. Kautschuk, v. 7, 1931, pp. 79-86 and 115-117.*

The experiments show that "sun-cracking" is not caused by sunlight but by at atmospheric O_3 , and takes place only when the rubber is under tension. Vulcanizates of different compounds under various degrees of elongation exposed to air and light showed maximum cracking at 10-20% elongation, and this cracking occurred at the same rate and was of the same nature when the experiments were repeated in darkness. The term sun-cracking should therefore be abolished in favor of atmospheric cracking. There was no cracking when the vulcanizates were not stretched. Exposure to air containing O_3 also caused cracking (again only when the samples were stretched), so that ultra-violet light is not necessary, and the explanation of Kearsley is untenable. There was no cracking on exposure in air containing nitrogen oxides, SO_2 and Cl . The formation of cracks by O_3 suggests a sensitive specific reaction for O_3 . Cracking does not depend upon the type of rubber, its degree of mastication, the coefficient of vulcanization, the particular filler or pigment or the particular accelerator, whereas the character of the stress-strain curves (modulus) has a determinant influence on the size and extent of cracking. No softener or organic diluent of numerous ones tested was of benefit when the O_3 concentration was above 0.003%, but below this concentration those which formed a surface bloom, e.g., paraffin, had a protective action. Fe applied in various forms to the surface (ink, rust, etc.) had no influence on cracking. A repetition of Williams' experiments on the prevention of cracking by $CuCl_2$ on the surface failed to confirm his results.

FABRICS

1981

1. Measurements of the Ageing of Linen Canvas. S. H. Hackney and G. Hedley. *Studies in Conservation*, v. 26, 1981, pp. 1-14.

Samples of linen canvas prepared in 1956 and kept in the Tate Gallery for 24 years were tested for tensile strength, acidity, reflectance and sulphur content. The samples included both unimpregnated linen and wax/resin impregnated linen. They were arranged so that some had been exposed to light and some protected from it. In addition a number of pieces within each sample were stored in a sealed Perspex-fronted container. Significant among the findings was that enclosing canvas in sealed containers had provided considerable protection against deterioration. Wax/resin impregnation of the samples aged in the open afforded similar protection, but there was also a small weakening effect in the same samples when they were enclosed.

1980

1. A Review of Air Pollutant Damage to Materials. J. E. Yocum and A. R. Stankunas. Draft Report to Environmental Criteria and Assessment Office, Office of Research and Development, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, December 1980, 92 pp. (Fe80-2)
2. Background and Principles of Long-Term Performance of Building Materials. S. E. Pihlajavaara. *Durability of Building Materials and Components*, ASTM STP 691, edited by P. J. Sereda and G. G. Litvan, American Society for Testing and Materials, 1980, pp. 5-16. (Fe80-4)
3. Critical Review of the Available Physicochemical Material Damage Functions of Air Pollution. M. Benarie. Report No. EUR-6643, Commission on the European Communities, 1980, 97 pp. (Fe80-8)
4. Design Determines Durability. G. K. Garden. *Durability of Building Materials and Components*, ASTM STP 691, edited by P. J. Sereda and G. G. Litvan, American Society for Testing and Materials, 1980, pp. 31-37. (MSC80-8)
5. Regional Air Pollution Study: Effects of Airborne Sulfur Pollutants on Materials. F. Mansfeld. NTIS Report PB81-126351, January 1980, 163 pp. (Fe80-18)

1979

1. The Effects of Weathering and Atmospheric Pollutants on Cotton Fabric and Cotton Fabric Treated With Selected Flame Retardants. I. Physical, Chemical, and Flammability Properties. B. L. Slaten, S. M. Spivak, and B. F. Smith. J. Appl. Polym. Sci., v. 23, No. 3, 1979, pp. 695-717.*

The effects of weathering and atmospheric pollutants on the physical, chemical, and flammability properties of cotton fabric treated with Pyrovatex 3805 (I) and with THPON-NH₃ flame retardant finished and untreated controls were determined. The fabrics were exposed to SO₂, NO₂, and O₃, singly and in combination, for 50, 100, and 150 hours in a 2500 W xenon arc Weather-Ometer using gas controls with and without light at 35° and relative humidity 90 percent. Excessive strength losses and large changes in d.p. for the untreated control occurred under all exposure conditions after 150 hours. Changes in the physical and chemical properties of the treated fabric were moderated by the finishes, with (I) providing better protection than THPON-NH₃. Elemental analysis and oxygen index measurements indicated that the (I) finish was severely degraded under these exposure conditions, with a resultant loss in flammability properties of the treated fabric after weathering. The THPON-NH₃ finish was not appreciably affected by these exposure conditions and the treated fabric retained most of its flammability properties after weathering.

2. The Effects of Weathering and Atmospheric Pollutants on Cotton Fabric and Cotton Fabric Treated With Selected Flame Retardants. II. Spectroscopic Studies. B. L. Slaten and B. F. Smith. J. Appl. Polym. Sci., v. 23, No. 2, 1979, pp. 367-380.*

The effect of weathering (exposure to Xe arc light and low concentrations of SO₂, NO₂, and O₃) on Pyrovatex 3805 or THPON-NH₃ fireproofing finishes on cotton were determined spectroscopically and were minimal. Solvent extraction of the finishes followed by infrared analysis using an internal reflectance procedure showed that the finishes removed from the fabric by the solvent were identical spectroscopically to the original finishes. The Fourier transform spectroscopy of the finishes on the fabric indicated that, with two exceptions, the weathering of the fabric and finishes caused no significant change in the structure of the flame-retardant finishes. The Fourier transform spectroscopy of Pyrovatex 3805 exposed to the combined weathering indicated a possible change in the phosphono structure of the finish.

1978

1. Deteriorative Effect of Sulfur Pollution on Materials. J. O. Nriagu. Chapt. I in Sulfur in the Environment, Part II: Ecological Impacts, edited by J. O. Nriagu, Wiley, New York, N.Y., 1978, pp. 1-59. (Fe78-11)

1977

1. Effects of Sulphur Dioxide on Materials. S. K. Gajendragadkar. Chem. Age India, v. 28, No. 8, 1977, pp. 673-677. (Fe77-5).
2. Effects on Economic Materials and Structures. J. E. Yocum and J. B. Upham, Chapt. 2 in Air Pollution, edited by A. C. Stern, Academic Press, New York, N.Y., v. 2, 1977, pp. 65-116. (Fe77-6)
3. Sorption of Sulfur Dioxide by Typical Indoor Surfaces Including Wool Carpets, Wallpaper, and Paint. M. Walsh, A. Black, A. Morgan, and G. H. Crawshaw. Atmos. Environ, v. 11, No. 11, 1977, pp. 1107-1111.*

The sorption of SO_2 from air by wool carpets, wallpapers, and painted surfaces was determined at a concentration of 100 to 200 $\mu\text{g}/\text{m}^3$. The deposition velocities for carpets were 0.02 to 0.07 cm/s and were lower for carpets with an acid pH than for those which were neutral or alkaline; the sorption was irreversible. Preexposing carpets to stable SO_2 equivalent to 27 years at 30 $\mu\text{g}/\text{m}^3$ reduced the amount of SO_2 taken up in a subsequent exposure by a factor of 3. Fresh emulsion paint had the highest (0.128) and vinyl wallpaper the lowest (0.007) deposition velocities of the other surfaces examined. Lower levels of SO_2 within buildings compared with outside are due to its sorption by furnishings.

1976

1. Air Pollution and Aspects of Polymer Degradation. I. Cook. ICCM Bulletin, v. 2, No. 4, December 1976, pp. 4-20. (E76-1)
2. Colorfastness to Light and Atmospheric Contaminants. J. E. Hemphill, J. E. Norton, O. A. Ofjord and R. L. Stone. Text. Chem. Color, v. 8, No. 4, 1976, pp. 60-62.*

A few dye-fiber combinations are adversely affected by the addition of atmospheric contaminants to lightfastness exposures. Synergistic effects are observed when 3 contaminants are used simultaneously which vary significantly from exposures of each component singly at the same concentration.

3. Conservation of Monuments. 2nd Session of the 29th National Congress of the Assoc. Termotecnica Italiana, Florence (September 25-27, 1974), Antonio Barbieri, Viale Premuda 2, Milano, 1976, 252 pp. (Italian). (OM76-4)
4. Effects of Gaseous Pollutants on Materials: A Chamber Study. F. H. Haynie, J. W. Spence, and J. B. Upham. NTIS Report PB-251580, 1976, 98 pp. (Fe76-5)

5. Effects of Power Plant Emissions on Materials. J. E. Yocom and N. Grappone. Research Corporation of New England, Wethersfield, Connecticut, NTIS Report PB-257539, July 1976, 85 pp. (Fe76-6)
6. Fading of Selected Drapery Fabrics by Air Pollutants. J. B. Upham, F. H. Haynie, and J. W. Spence. J. Air Pollut. Control Assoc., v. 26, No. 8, 1976, pp. 790-792.

Three fabrics were exposed to sulfur dioxide (0.03 and 0.50 ppm), nitrogen dioxide (0.05 and 0.50 ppm), and ozone (0.08 and 0.50 ppm) at 50 and 90 percent relative humidity. The royal blue and red fabrics were 66 percent rayon, 34 percent acetate. The plum fabric was 100 percent cotton duck. Measurements of the effects of exposure were made after 250, 500, and 1000 hours. The plum fabric was the only drapery fabric significantly affected by any of the pollutants. Nitrogen dioxide contributed directly and synergistically with relative humidity to increased fading rates. The amount of fading that occurred after 1000 hours of exposure was easily detected visually. The results showed that the useful life of the plum fabric would be reduced by 19 percent when exposed to the annual average nitrogen dioxide primary air quality standard of 100 $\mu\text{g}/\text{cu m}$. Because only one of three fabrics was appreciably faded by any of the three pollutants, product selection rather than pollution abatement is probably the most economic solution to the fading problem.

7. Physical and Economic Damage Functions for Air Pollutants by Receptor. B. Liu and E. S. Yu. Report No. EPA-600/5-76-011, Environmental Protection Agency, September 1976, 172 pp. (Fe76-13)

1975

1. Artificial Aging of Yarns in Presence as Well as in Absence of Light and Under Different Atmospheric Conditions. J. E. Leene, L. Demy, R. J. Elema, A. J. de Graaf, and J. J. Surtel. ICOM Committee for Conservation, 4th Triennial Meeting, Venice (October 1975), published by the Int. Council of Museums, Paris, No. 10-2, 1975, 11 pp.

Several natural textile materials have been subjected to artificial aging processes. The influence of light, temperature, humidity, air pollutants, several pre-treatments, and combinations of these factors have been investigated. The results are discussed in general, and conclusions and recommendations are given for storage and exhibition of textile museum objects.

2. Effect of Air Pollution on Cotton Awning Fabric. R. J. Brysson, A. M. Walker, A. S. Cooper, Jr., and D. C. Hunter. Text. Res. J., v. 45, No. 2, 1975, pp. 154-159.**

Experimental and conventional cotton awning fabrics exposed at six different sites in New York State for 2 years showed that in areas of relatively unpolluted air the fabrics lost less strength than when exposed to high levels of SO_2 and airborne soiling contaminants. CO and photochemical oxidants in the air did not significantly accelerate degradation of the fabrics. Fabrics treated with experimental $\text{ZnO-Cu(BO}_2)_2$ finishes degraded at somewhat lower rates than did untreated controls, but when used in conjunction with standard vinyl coatings appeared to adversely affect durability. Conventionally treated vinyl-coated awning fabrics were most resistant to degradation.

3. Effects of Air Pollutants on Textile Fibers and Dyes. J. B. Upham and V. S. Salvin. NTIS Report PB-241507, February 1975, 88 pp.

This document presents: (1) a comprehensive survey of the damaging effects of air pollutants (particulates, SO_x , and ozone) on textile fibers and dyes, and (2) the results and assessment of a public opinion survey to primarily measure consumer awareness of the detrimental effects of air pollution on household textile products. The survey found that air pollution represents a significant problem area for the textile industry and many consumers. The public opinion survey revealed that consumer awareness of the major air pollution effects on household textile products is poorly established and generally lacking.

4. Environmental Exposure System for Studying Air Pollution Damage to Materials. J. W. Spence, F. D. Stump, F. H. Haynie, and J. B. Upham. NTIS Report PB-240615/5ST, 1975, 46 pp. (Fe75-11)
5. Sulfur Dioxide and Material Damage. D. G. Gillette. J. Air Pollution Control Assn., v. 25, No. 12, December 1975, pp. 1238-1243. (Fe75-17)

1974

1. Design of a Laboratory Experiment to Identify the Effects of Environmental Pollutants on Materials. J. W. Spence and F. H. Haynie. Corrosion in Natural Environments, ASTM STP 558, American Society for Testing and Materials, 1974, pp. 279-291. (Fe74-10)
2. Effects of Oxidative Components of Air Pollutants on the Degradation of Polymers. F. Flajsman. Kem. Ind., v. 23, No. 2, 1974, pp. 96-100 (Croatian). (E74-3)
3. The Economic Damages of Air Pollution. T. E. Waddell. NTIS Report PB-235701, 1974, 156 pp. (Fe74-21)

4. The Economics of Clean Air In Perspective. F. H. Haynie. Materials Protection and Performance, v. 13, No. 4, April 1974, pp. 33-38. (Fe74-22)
5. The Environment and Collections (Part 2). G. W. Rogers. Canadian Conservation Institute Newsletter, No. 5, November 1974, pp. 2-3. (OM74-16)

1973

1. Concentrations, Decay Rates, and Removal of Ozone and Their Relation to Establishing Clean Indoor Air. R. H. Sabersky, D. A. Sinema, and F. H. Shair. Environ. Sci. Technol., v. 7, No. 4, 1973, pp. 347-353. (OM73-2)
2. Fading of Dyed Fabrics Exposed to Air Pollutants. N. J. Beloin. Text. Chem. Color., v. 5, No. 7, 1973, pp. 128-133.**

Nitrogen dioxide, ozone, and to a lesser extent sulfur dioxide caused fading on dyed fabrics, while nitric oxide had little effect. High temperature and relative humidity increased the degree of fading, and the rate of fading was nonlinear. Fabric samples woven from natural and synthetic fibers were dyed with common direct acid, basic, reactive, disperse, azo, and vat dyes. These fabrics were exposed 12 weeks to low and high concentrations of the pollutants corresponding to average urban atmospheres at high and low temperatures and relative humidity in the abundance of light.

3. Study of Some Factors Affecting the Photodegradation of Textile Yarns. I. The Spectral Distribution of Sun-Sky and Xenon-Arc Radiation. L. M. Lock, G. C. Frank, and J. R. Stevens. Textile Res. J., v. 43, No. 8, 1973, pp. 483-488.

A detailed study was made of the relative spectral distribution of sun-sky radiation at several times of day under various sky conditions from June to October 1971. A sufficient number of spectra were recorded to provide a statistically viable sample. Average spectral distributions for three daily time periods and four classes of sky conditions within four approximately monthly periods were calculated and compared.

1972

1. Fading of Dyed Fabrics by Air Pollution. N. J. Beloin. Text. Chem. Color., v. 4, No. 3, 1972, pp. 77-82.**

Evaluation of the colorfastness of 67 dye-fabric combinations exposed to atmospheric gases in the absence of sunlight yielded fading in 64

percent of the cases. Comparison of parallel urban-rural area samples by analyses of variance showed significantly greater fading in the urban areas and multiple regression analysis of pollutant concentrations indicated that sulfur dioxide, nitrogen dioxide, and ozone are primary causes of fabric fading. Analyses were based on 6,000 color difference measurements of samples exposed for 3-month periods.

1971

1. Present Status and Prospects on Air Pollution. U. Bardelli. Ingegneria, v. 5, 1971, pp. 311-316 (Italian). (Fe71-19)

1970

1. Interstate Surveillance Network--1969 Data. Division of Air Quality and Emission Data, Report No. NAPCA/APTD 70-3, by U.S. Department of Health, Education, and Welfare, May 1970, 203 pp. (OM70-5)

2. Reaction of Cellulosic Fabrics to Air Contaminated With Sulfur Dioxide. S. H. Zeronian. Text. Res. J., v. 40, 1970, pp. 695-698.

Cotton, viscose rayon, and high-wet-modulus rayon fabrics exposed to air containing 0.1 ppm of sulfur dioxide and simultaneously to light from a xenon arc lamp showed an additional loss in the breaking strength cycle compared with the loss in air and light alone. The treated fabrics were compared with similar samples degraded by hydrolysis in dilute sulfuric acid. Durable press-finish cotton showed no loss in yarn strength when exposed to light plus air or to light plus air containing sulfur dioxide.

3. Reaction of Fabrics Made From Synthetic Fibers to Air Contaminated With Nitrogen Dioxide, Ozone, or Sulfur Dioxide. S. H. Zeronian, K. W. Alger, and S. T. Omaye. 2d Int. Union Air Pollut. Prev. Ass. Int. Clean Air Congr. (Washington), Paper CP-25E, December 6-11, 1970, 28 pp.

In an experimental study, the breaking load, rupture energy, and breaking extension of nylon yarn were markedly reduced by the presence of sulfur dioxide during light exposure in the Weather-Ometer. The results showed that sulfur dioxide can attack nylon without the presence of particulate matter and that degradation is not due to acid hydrolysis following conversion of sulfur dioxide to sulfuric acid. Modacrylic and polyester fabrics were not affected by sulfur dioxide; acrylics, nylon, and polyester fabrics may be somewhat affected by nitrogen dioxide and ozone.

4. Systems Analysis of the Effects of Air Pollution on Materials. R. L. Salmon. NTIS Report PB-209192, January 15, 1970, 196 pp. (Fe70-13)

1969

1. Mechanisms of Sulfur Dioxide Absorption by Natural and Synthetic Textile Fibers. C. J. Gregory and R. M. Manganelli. Air Pollution Control Assn, 62nd Annual Meeting, Paper 69-200, June 22-26, 1969, 25 pp.

Laboratory studies were conducted to determine the mechanism of atmospheric sulfur dioxide removal by undyed fibers of wool, viscose rayon, nylon and cotton. Textile fibers removed atmospheric sulfur dioxide at rates directly proportional to their moisture contents when these moisture values were less than the saturation values. The sulfur dioxide removal capacity of textile fibers, based on the rate and extent of gas absorption, was largest for wool and smallest for nylon. Comparisons were made between sulfur dioxide absorption rates for water and suspensions of fibers in water.

2. Testing Atmospheric Fading of Dyed Cotton and Rayon. V. S. Salvin. Amer. Dyestuff Reporter, v. 58, No. 21, October 20, 1969, pp. 28-29.

Although the fading of dyed cellulose acetate, nylon and polyester fabrics by atmospheric contaminants is well known and the subject of vast volumes of research work, similar fading of dyed cellulose and viscose rayon fabrics is not recognized as such when complaints are registered. The reasons for this information gap are threefold:

- (1) The published finding on this phenomenon are relatively recent.
- (2) The fading complaints are falsely attributed to the effect of sunlight.
- (3) The AATCC test methods for fading caused by oxides of nitrogen (gas fading) do not show the fading changes experienced in actual service.

Complaints of atmospheric fading on fabrics and garments in warehouses and on retailers shelves have been reported for cottons and rayons involving (a) cellulosic direct dyes, (b) vat dyes, (c) sulfur dyes, and (d) reactive dyes.

1968

1. Durability of Cotton Textiles: Effects of Exposure in Contaminated Atmospheres. R. J. Brysson, B. J. Trask, and A. S. Cooper, Jr. Amer. Dyest. Rep., v. 57, No. 14, 1968, pp. 512-517

A direct correlation was shown between air pollution and accelerated degradation of exposed cotton fabrics. In contaminated areas, the degradation rate was several times that of the less polluted areas. In laboratory studies, acid-impregnated fabrics exposed to an artificial light source showed an accelerated rate of degradation. When laboratory samples were additionally contaminated with artificial soot (lampblack), the rate of degradation was further accelerated.

1967

1. Corrosion by Air Pollution. J. R. Goss. Proc. Annu. Conf., Nat. Soc. Clean Air, No. 34, 1967, pp. 75-92. (Fe67-4)
2. Effects of Air Pollution on Exposed Cotton Fabrics. R. J. Brysson, B. J. Trask, J. B. Upham, and S. G. Booras. J. Air Pollution Control Association, v. 17, No. 5, May 1967, pp. 294-298.

This report covers results of 1 year exposure studies of cotton fabrics exposed at different environmental sites in metropolitan St. Louis, Missouri and Chicago, Illinois areas. Twelve sites, ranging from heavy industrial to essentially rural, were used. Data presented establish relationship between air pollution and accelerated degradation of fabrics. This data includes strength retention of several cotton fabrics and air pollution data, as determined by periodic measurements of dustfall, suspended particulate matter, sulfation, and sulfur dioxide.

3. Effects of Air Pollution on the Fading of Dyed Fabrics. R. L. Ajax, C. J. Conlee, and J. B. Upham. J. Air Pollut. Contr. Assoc., v. 17, No. 4, April 1967, pp. 220-224.**

Experiments with 69 fabric-dye combinations exposed for 6 days in the absence of light to auto exhaust, uv-irradiated auto exhaust, uv-irradiated auto exhaust plus SO₂, or clean air plus SO₂, for 9 hrs/day, indicated that uv-irradiated auto exhaust caused fading in 16 of the combinations, and uv-irradiated auto exhaust plus SO₂ caused fading in 20 of the combinations. Unirradiated auto exhaust or clean air plus SO₂ caused no appreciable fading in any sample. The 69 combinations were exposed for 3 months in spring and summer in the absence of light to the atmosphere of Los Angeles and Santa Paula, California, Chicago and Argonne, Illinois, Washington, D.C., and Poolesville, Maryland, Tacoma and Purdy, Washington, Sarasota, Phoenix, and Cincinnati. Fading was pronounced for 17 of the combinations, particularly at Los Angeles, Chicago, and Washington, D.C. There was little fading at Purdy, Phoenix, and Sarasota, indicating that concentration of air pollutants, rather than differences in temperature and humidity, determine degree of fading. Fading was highest in Chicago in the spring and in Los Angeles in the summer, seasons in which air pollution is greatest for these cities. For the 17 combinations which exhibited pronounced fading, fading was greater at urban sites than at corresponding rural sites. Fading was measured by using a Hunter Association Model D25A color difference meter and results were expressed in D. B. Judd units.

4. The Weathering of Cotton, Nylon, and Terylene Fabrics in the United Kingdom. A. H. Little and H. L. Parsons. J. Text. Inst., v. 58, 1967, pp. 449-462.

Fabrics were exposed at eight sites in the United Kingdom where various degrees of air quality existed. Meteorological conditions were recorded at each site.

5. The Effects of Photochemical Oxidants on Materials. L. S. Jaffe. J. Air Pollution Control Association, v. 17, No. 6, 1967, pp. 375-378. (E67-3)

1966

1. The Effects of Atmospheric Conditions on Specific Cotton Fabrics. M. A. Morris. California Agricultural Experiment Station, Bulletin 823, 1966, 29 pp.

In all outdoor and many indoor uses of cotton textiles the aggregate effect of atmospheric conditions is destructive. These conditions, often called "weathering", include such environmental factors as sunlight, atmospheric pollutants, moisture, and wind. When cotton is exposed to these elements, it deteriorates in strength and appearance until ultimately replacement becomes necessary.

The degradation of cotton by various atmospheric conditions is of interest to consumers and technologists. Because of the many end-uses, cotton fabrics are subjected to a wide range of weather conditions. In addition, cotton is the principal fiber used in outdoor fabrics. Even for fabrics used indoors, atmospheric conditions can affect serviceability.

Within the western portion of the United States extreme differences in atmospheric conditions exist because of variations in the amount and intensity of sunlight, in the amount and distribution of precipitation, altitude, and other factors. The western states are therefore in a unique position, through cooperative research, to study the deleterious effect of outdoor exposure on cotton fabrics.

In this study cotton fabrics were exposed outdoors to natural weathering and in the laboratory to artificial weathering conditions. The cotton was exposed, up to four months, outdoors at six locations differing widely in geographic and climatic conditions. Laboratory exposures to selected components of weathering, i.e. light, heat and humidity, ozone, and air movement, were made for periods up to 900 or 1,100 hours.

1965

1. Fading of Coloring Matters. C. H. Giles. J. Appl. Chem., v. 15, No. 12, 1965, pp. 541-550.*

Influences which affect the permanence of dyed textiles, films, etc., were described, but for making practical suggestions to prolong the life of museum specimens little can be added to Russel and Abneys recommendations (Report to the Science and Art Dept. of the Committee of Council on Education, London: H.M.S.O., 1888) made 77 years ago.

2. Materials Deterioration and Air Pollution. J. B. Upham. J. Air Pollution Control Associations, v. 15, No. 6, June 1965, p. 265. (Fe65-14)

1964

1. Relation of Atmospheric Contaminants and Ozone to Lighfastness.
V. S. Salvin. Am. Dyestuff Reporter, v. 53, No. 1, January 6, 1964,
pp. 33-41.

The effect of atmospheric contaminants--oxides of nitrogen, sulfur dioxide and ozone--in causing dye fading is shown for various dyes on cotton, rayon, nylon, acetate, polyester, acrylics, and wool. Data are given for exposures in various parts of United States. Potential contribution of atmospheric contaminants as variables in lightfastness testing is shown in series of dyes exposed simultaneously in the presence and absence of sunlight. Three recommendations or test procedures are included.

1963

1. Effect of Air Pollutants on Dyed Fabrics. V. S. Salvin. J. Air Pollution Control Assoc., v. 13, No. 9, 1963, pp. 416-422.

The results of exposure of a range of dyes on various fibers in Los Angeles, Chicago, Phoenix, and Sarasota can be correlated with the contaminants present. The results correlate closely with results of laboratory test methods used to predict performance. Exposure in the air-pollution area of Los Angeles shows fading on dyes vulnerable to nitrogen oxides and O_3 . In Chicago, the presence of SO_2 , which results in greater absorbed acidity, and the low O_3 content gives fading differences. In Sarasota, only O_3 fading is noted. The high humidity is responsible for greater changes than observed in Phoenix. Exposure to irradiated auto exhaust gases under controlled conditions gives fading results which are equivalent to service exposure in Los Angeles.

1959

1. Deterioration of Materials in Polluted Atmospheres. J. E. Yocum.
Corrosion, v. 15, No. 10, October 1959, pp. 541t-545t. (Fe59-5)

1957

1. The Effects of Air Pollution on Buildings and Metalwork. R. J. Schaffer.
Air Pollution, edited by M. W. Thring, Butterworth Scientific, London,
1957, pp 58-71. (Fe57-5)

1955

1. Action of Acids on Cotton and Rayon. H. Baier. Melliand Textilber, v. 36, 1955, pp. 261-265.

The glucosidic linkage of cellulose is in its acetal form, which is particularly sensitive to acid degradation. In this degradation H_2O is added, causing an increase in reducing power of the formed "hydrocellulose" and a decrease in fiber strength. The influence of time, temperature, addition of neutral salts and the concentration, and strength and dissociation constant of the acid on the degree of degradation is discussed. Determination of the $KMnO_4$ number is simpler and faster than that of the polymerization value. Increase of that number by 14.7 indicates that 1 percent cellulose has been degraded. Values that indicate 1 percent or more of degradation are signs of danger.

2. Corrosion Aspects of Air Pollution. L. Greenburg and M. B. Jacobs. Amer. Paint J., v. 39, No. 43, 1955, pp. 64-78. (Fe55-2)
3. The Destructive Effects of Air Pollution on Materials. A. Parker. 6th Des Voeux Mem. Lecture, Proc. 22nd Annual Conf., Nat. Smoke Abatement Soc., Bournemouth, England, September 28, 1955, pp. 120-132. (Fe55-6)

1954

1. Deterioration of Materials--Causes and Preventive Techniques. G. A. Greathouse and C. J. Wessel. Reinhold Publishing, New York, N.Y., 1954, 835 pp. (OM54-1)

1952

1. The Oxidation of Cellulose by Ozone in Small Concentrations. H. Bogaty, K. S. Campbell and W. D. Appel. Textile Research J., v. 22, 1952, pp. 81-83.*

Ozone in amounts likely to occur in air at the earth's surface (up to 0.06 ppm) deteriorates cotton textiles when wet. The deterioration is slight when compared with "weathering" elements such as light, heat, wetting and drying, and microorganisms. Fifty-day exposure to air containing 0.02-0.06 ppm of O_3 reduces the breaking strength of wet print cloth 20% and increases the fluidity in cuprammonium solution from 8 to 16 rhes. When exposed dry, the cloth underwent little or no change in these characteristics. Increased ozone content causes increases in cellulose deterioration.

1950

1. Ease of Soiling of Fabrics. J. Henno and R. Jouhet. Bull. Inst. Textile France, No. 17, 1950, pp. 63-65.

Soiling by air-borne dust is accomplished under controlled conditions. An air blower carries a weighed sample of soil from a metal screen to a pad of the fabric under evaluation, at a measured air pressure. After shaking to remove surface accumulation, retained soil is evaluated photometrically.

1940

1. Atmospheric (Gas) Fading of Colored Cellulose Acetate. C. A. Seibert. Am. Dyestuff Reprtr., v. 29, No. 15, 1940, pp. P363-P374.

Color destruction is established as caused by the presence in the atmosphere of oxides of nitrogen. Experimental procedures are outlined and the use of inhibitors is discussed. Dyes which are diazotized and developed after application to the acetate fibers exhibit the best resistance to atmospheric fading. Next best are the azo dyes, many of which are water-soluble and applicable in a l-bath operation. The most sensitive, in general, is aminoanthraquinones, which are applied in a dispersed form. There are very few dyes which, after application to the acetate fiber, are definitely not affected by prolonged exposure in an atmosphere containing oxides of nitrogen.

1939

1. Effect of Sulfur Compounds in the Air on Various Materials. L. R. Burdick and J. F. Barkley. U.S. Bureau of Mines, I.C. 7064, April 1939, 9 pp. (Fe39-1)

1937

1. The Fading of Dyeings on Cellulose Acetate Rayon. F. M. Rowe and K. A. J. Chamberlain. J. Soc. Dyers Colourists, v. 53, 1937, pp. 268-278.*

It is probable that the decomposition that occurs in "fading" may be due primarily to diazotization, nitrosation, or oxidation of the coloring matters or their salts on the fiber. Subsequent decomposition of the resulting products may then proceed in various directions under the influence of light, moisture or acids. Oxides of nitrogen, SO_2 , H_2SO_4 , oxygen and water may all be involved in the ultimate decomposition of cellulose acetate-rayon dyes by burnt gas fumes with the nitrogen oxides present in the fumes. The experiments were carried out on 18 anthraquinoid dyes. Conclusions: The combustion of coal gas or other

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fuel, or the use of electric heating elements or other red hot materials, in air produces oxides of nitrogen by oxidation of atmospheric nitrogen. Nitrogen oxides accelerate the oxidation of SO_2 to SO_3 in the presence of water vapor. Conditions should be standardized for determining the fastness of dyeings to actual burnt gas fumes. SO_2 alone has little effect but is capable of modifying the action of oxides of nitrogen on the dyes considerably. Thus, the action of controlled quantities of NaNO_2 , NaHSO_3 and H_2SO_4 on cellulose acetate rayon approaches the effect produced by burnt gas fumes. A test based on the use of these reagents is outlined and may be employed as a rapid preliminary method for evaluating the fastness of new dyes to burnt gas fumes with subsequent confirmation by the use of actual burnt gas fumes.

PAINTS

1982

1. Acid Rain: Impacts on the Natural and Human Environment. H. C. Martin. Materials Performance, v. 21, No. 1, January 1982, pp. 36-39. (Fe82-3)
2. Atmospheric Corrosion of Fastener Joints. E. Taylor. Extended Abstracts, International Symposium on Atmospheric Corrosion (October 5-10, 1980, Hollywood, Florida), Electrochemical Society, v. 80-2, 1980, pp. 609-610. (Fe82-7)
3. Atmospheric Corrosion of Metals Under Moving Conditions. J. D. Talati and B. M. Patel. Atmospheric Corrosion, edited by W.H. Ailor, Wiley, New York, N.Y., 1982, pp. 695-704. (Fe82-10)
4. Atmospheric Corrosion Testing in Australasia. J. F. Moresby, F. M. Reeves and D. J. Spedding. Atmospheric Corrosion, edited by W.H. Ailor, Wiley, New York, N.Y., 1982, pp. 745-754. (Fe82-15)
5. Atmospheric Corrosion Testing in Brazil. A. C. Dutra and R. Vianna. Atmospheric Corrosion, edited by W.H. Ailor, Wiley, New York, N.Y., 1982, pp. 755-774. (Fe82-16)
6. Atmospheric Corrosion Testing In The Federal Republic Of Germany. G. Oelsner. Atmospheric Corrosion, edited by W.H. Ailor, Wiley, New York, N.Y., 1982, pp. 797-806. (Fe82-18)
7. Atmospheric Corrosion Testing in Norway. L. Atteraa and S. Haagenrud. Atmospheric Corrosion, edited by W.H. Ailor, Wiley, New York, N.Y., 1982, pp. 873-892. (Fe82-20)
8. Atmospheric Corrosion Testing in Southern Africa. B. G. Callaghan. Atmospheric Corrosion, edited by W.H. Ailor, Wiley, New York, N.Y., 1982, pp. 893-912. (Fe82-21)

9. Automotive Corrosion in India. G. V. Ramanaiah, S. D. Chirputkar and B. L. Dhar. Atmospheric Corrosion, edited by W.H. Ailor, Wiley, New York, N.Y., 1982, pp. 711-716. (Fe82-26)
10. Economic Assessment of Pollution Related Corrosion Damage. F. H. Haynie. Atmospheric Corrosion, edited by W. H. Ailor, Wiley, New York, N.Y., 1982, pp. 3-18. (Fe82-33)
11. Rapid Methods for Determining Atmospheric Corrosivity and Corrosion Resistance. D. P. Doyle and T. E. Wright. Atmospheric Corrosion, edited by W.H. Ailor, Wiley, New York, N.Y., 1982, pp. 227-244. (Fe82-45)

1981

1. Acid Rain: Impacts on the Natural and Human Environment. H. C. Martin. Paper No. 114, Corrosion/81 (Toronto, Canada), National Association of Corrosion Engineers, Houston, TX, April 6-10, 1981, 7 pp. (Fe81-1)

1980

1. A Review of Air Pollutant Damage to Materials. J. E. Yocum and A. R. Stankunas. Draft Report to Environmental Criteria and Assessment Office, Office of Research and Development, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, December 1980, 92 pp. (Fe80-2)
2. Alteration in Properties of Organic Coatings for Buildings Due to the Leaching Process. D. Y. Perera and D. V. Eynde. Durability of Building Materials and Components, ASTM STP 691, edited by P. J. Sereda and G. G. Litvan, American Society for Testing and Materials, 1980, pp. 698-710.

Changes in water transport mechanism and in mechanical properties of organic coating for buildings due to the leaching process are discussed. The water transport mechanism was investigated by measuring vapor and liquid water permeation and absorption-desorption. Mechanical properties, namely stiffness and the values of strain and stress at yield point and at break, were determined by stress-strain tests. Six different types of

organic coatings were investigated, namely, two emulsion paints, a vinyl toluene acrylic, a polyurethane, a vinyl, and a textured paint. As a result of the leaching process, mechanical properties and properties describing the material characteristics with respect to moisture were affected. These changes were more pronounced in the case of water-borne paints. This means that the results obtained with freshly made paints have to be interpreted cautiously, especially if the aim is to predict the paint durability in practice. In order to make laboratory measurements as relevant as possible to environmental conditions, a number of conditions are proposed.

3. Background and Principles of Long-Term Performance of Building Materials. S. E. Pihlajavaara. Durability of Building Materials and Components, ASTM STP 691, edited by P. J. Sereda and G. G. Litvan, American Society for Testing and Materials, 1980, pp. 5-16. (Fe80-4)
4. Critical Review of the Available Physicochemical Material Damage Functions of Air Pollution. M. Benarie. Report No. EUR-6643, Commission on the European Communities, 1980, 97 pp. (Fe80-8)
5. Design Determines Durability. G. K. Garden. Durability of Building Materials and Components, ASTM STP 691, edited by P. J. Sereda and G. G. Litvan, American Society for Testing and Materials, 1980, pp. 31-37. (MSC80-8)
6. Durability of Colorants for Plastic Building Products. T. B. Reeve. Durability of Building Materials and Components, ASTM STP 691, edited by P. J. Sereda and G. G. Litvan, American Society for Testing and Materials, 1980, pp. 731-737.

Colorants are used widely in a variety of today's building materials, or in coatings applied thereon, to protect or decorate the finished product. Durability is a frequent requirement of the colorant, but few appreciate the many considerations that enter into its selection for this purpose.

This paper describes aspects of durability that may be important to the appearance and long-term life of the product, and the many factors of formulation and use that influence performance. Means of determining durability, including common pitfalls of accelerated testing, are discussed, and typical performance of commonly used colorants are reviewed.

7. Durability of Some Common Building Materials. W. H. Gutt and L. H. Everett. Durability of Building Materials and Components, ASTM STP 691, edited by P. J. Sereda and G. G. Litvan, American Society for Testing and Materials, 1980, pp. 131-144. (Fe80-10)
8. Emulsion-Based Paint Systems For Wood. O. C. Vorster. Durability of Building Materials and Components, ASTM STP 691, edited by P. J. Sereda

and G. G. Litvan, American Society for Testing and Materials, 1980, pp. 711-720.

The paper deals with the durability of experimental emulsion-based systems on wood exposed to weathering for a period of 3 years. A number of oleo-resinous and emulsion-based primers were applied to two different types of timber and overcoated with both conventional oleoresinous and emulsion-based topcoats. Four different exposure sites representing four different climatic regions were chosen to allow a study of the influence of the following on the durability of the coating systems: the composition of the paint system, the primer formulation, the topcoat formulation, and the climatic conditions. It was found that emulsion-based systems could be more durable than the more conventional systems.

9. Examination of Durability Test Methods for Building Materials Based on Performance Evaluation. T. Nireki. Durability of Building Materials and Components, ASTM STP 691, edited by P. J. Sereda and G. G. Litvan, American Society for Testing and Materials, 1980, pp. 119-130. (Zn80-5)
10. Regional Air Pollution Study: Effects of Airborne Sulfur Pollutants on Materials. F. Mansfeld. NTIS Report PB81-126351, January 1980, 163 pp. (Fe80-18)
11. Selection of Paints and Coatings Used in Civil Engineering and For Road Safety. A. M. Serres. Durability of Building Materials and Components, ASTM STP 691, edited by P. J. Sereda and G. G. Litvan, American Society for Testing and Materials, 1980, pp. 721-730.

In the field of the anti-corrosion protection of metal structures (bridges, lock gates, lamp posts, etc.) and the painting of concrete, artificial aging tests are employed in an attempt to select products and systems of products that can ensure the desired service life (generally at least ten years). While great care must be taken in performing these tests, in particular where their reproducibility is concerned, it is their interpretation that is the most tricky task; they must be interpreted prudently, with the aid of mechanical tests and in the light of experience on the actual site.

Where the marking of pavements is concerned, this type of test has had to be abandoned, for it is not possible to reproduce properly in the laboratory the simultaneous effect of mechanical wear due to traffic and the effect of weathering. The rating obtained in the laboratory is different from that obtained on the road, especially in view of the wide diversity of products employed. So at the present time a road test of quality is being used for these products in France. A study also is being made of the use of a circular test track.

12. The Meaning of Durability and Durability Prediction. G. Frohnsdorff and L. W. Masters. Durability of Building Materials and Components, ASTM

STP 691, edited by P. J. Sereda and G. G. Litvan, American Society for Testing and Materials, 1980, pp. 17-30. (Fe80-19)

1979

1. Damage to Painted Objects in Swedish Churches--A Report on the Situation. Restoration Principles. P. Tangeberg. Fornvannen, No. 74, 1979, pp. 113-125 (Swedish).

The Central Board of National Antiquities carried out a survey of the damage to paintings and painted and gilded objects in fifty-five Swedish churches. Almost 90 percent of all older objects painted on wood were in need of conservation. Causes of damage are identified; particularly modern heating systems and inadequate restoration (Sweden lacks both conservation training programs and organized conservation activities).

2. Polymeric Facade Paints for Restoration of Historic Objects. Prague Inst. of Chem. Tech., Prague, Czechoslovakia, 1979, 38 pp. (Czech).

Proceedings of the seminar "Polymeric Facade Paints for Restoration of Historic Objects" organized by the Artistic Works Restoration Research Laboratory, Prague Institute of Chemical Technology in Prague, 1979. The book contains six papers dealing with composition and properties of polymeric facade paints, testing methods for these materials, and the effect of air pollution on plasters with polymeric cements. Properties of natural lime are also briefly mentioned.

3. Results of 30 Months Atmospheric Corrosion Testing in St. Louis, Mo., USA. F. Mansfeld. Reliability of Materials for Solar Energy--Workshop Proceedings, CONF-781228, v. 2, Pt. 1, October 1979, pp. 627-657. (Fe79-7)

1978

1. Anti-Graffiti Coatings. M. A. Post, M. Godette, and P. G. Campbell. Modern Paint Coatings, v. 68, No. 2, 1978, pp. 28-35.

Previous experience in the use of anti-graffiti paints is briefly reviewed and used to determine the properties required of these systems. Forty-seven acrylate, urethane, epoxy, silicone, polyester and vinyl graffiti-resistant coatings were analyzed for resin type to determine if any correlation between resin type and performance existed, but none was apparent. Further tests were conducted on the paints' resistance to ultraviolet, moisture, abrasion, graffiti removers and spray paint. The flexibility of the paint was also considered in terms of the substrate to be painted.

2. Certain Epoxies, Fluorocarbon-Acrylics, and Silicones as Stone Preservatives. K. L. Gauri and M. A. Rao. Decay and Preservation of Stone: Engineering Geology Case Histories, No. 11, edited by E. M. Winkler, Geological Soc. of America, 1978, pp. 73-79.

Marble and limestone specimens were treated (surface coatings and in-depth impregnations) with selected polymers and tested for their chemical resistance to attack by gaseous CO₂ and SO₂ and carbonic and sulfurous acids. They were also tested for their mechanical soundness using sodium sulfate test. Epoxy impregnated specimens having fluoropolymer surface coatings produced the best results.

3. Deteriorative Effect of Sulfur Pollution on Materials. J. O. Nriagu. Chap. 1 in Sulfur in the Environment, Part II: Ecological Impacts, edited by J. O. Nriagu, Wiley, New York, N.Y., 1978, pp. 1-59. (Fe78-11)
4. Polyvinyl Acetates for the Protection, Treatment, and Conservation of Historical Objects of Stone and Other Materials (Research Work and Examples of Application). R. J. Bilinski and B. Penkala. Proc. 5th ICOM Committee for Conservation, Zagreb, 1978, pp. 1-8.

The aim of the investigation was the synthesis in poly(vinyl acetate)s specially intended for the conservation and protective coating of historical objects made of stone and other materials. Poly(vinyl acetate)s were used as preservatives for test samples of the materials collected from historical objects, which were next exposed to rough atmospheric conditions. Important examples of the treatment and the effects of the conservation work accomplished are presented.

5. The Results of a Thirty-Month Exposure Study of Steels and Other Materials to Airborne Sulfur Pollutants in St. Louis, Missouri. F. Mansfeld. Corrosion/78, National Association of Corrosion Engineers, Houston, Tx., Paper No. 88, 1978, 16 pp. (Fe78-21)
6. Water Vapor Permeation Through Clear Coatings. M. Yaseen and E. E. Ashton. J. of Coating Tech., v. 50, No. 645, 1978, pp. 50-59.

Permeability of resin coatings to water vapor is discussed in terms of composition and molecular structure of the coating material, as well as in relation to the effects of relative humidity and temperature. The resins studied are clear phenolic and alkyd coatings. A general description of the theory of permeation is presented.

1977

1. Effects of Sulfur Dioxide on Materials. S. K. Gajendragadkar. Chem. Age India, v. 28, No. 8, 1977, pp. 673-677. (Fe77-5)

2. Examination of a New Method for the Cleaning and Conservation of Medieval Glass Paintings Used in Chartres. J. C. Ferrazzini. *Maltechnik/Restauro*, v. 83, No. 3, 1977, pp. 145-154 (German).

The new process of preserving medieval glass paintings with a protective coating of Viacryl has some grave shortcomings. For one, cleaning glass with ion-selective agents injures the substratum and makes it more vulnerable to corrosion. For another, coatings of Viacryl are permeable to water and sulfur dioxide, and thus do not provide adequate protection against corrosion. However, it is extraordinarily resistant to weather.

Removal of the protective coating is very difficult and hazardous, and therefore the treatment must be considered practically irreversible. When Viacryl is applied in thin layers, it is exceptionally fire resistant and possesses good pyrotechnical properties. A new prophylactic measure is introduced here as an alternative method for preserving medieval glass paintings. Research on this new method is continuing.

3. Rapid Weathering of Wood and Paintings Under the Additional Influence of SO_2 . A. Uwe and G. Uwe. *Staub Reinhalt Luft*, v. 37, No. 2, February 1977, pp. 53-55 (German).

For research of working mechanisms and possible protections within the scope of air pollution control, a weathering device is described which was altered for additional application. As experiments on wood and vehicle body work surfaces show, this modified Gardner wheel allows fumigations which, in a short time, make facts about the effects of air pollution known. Sulfur dioxide caused changes in color and gloss of the materials examined.

4. Relation Between Mass Wear of Organic Protective Coatings and Meteorological Data. W. D. Kaiser. *Korrosion (Dresden)*, v. 8, No. 1, 1977, pp. 3-15 (German).

Although atmospheric conditions (that is, pollution, particularly SO_2 , duration of sunlight, precipitation, temperature) have a pronounced effect on the corrosion of unprotected steel, they have no such marked effect on the wear of protective coatings. Wear, as measured by film thickness, is affected by duration of sunlight, precipitation, and temperature in decreasing order of importance. Wear of paints containing either binders or pigments, which are converted by SO_2 to readily soluble products, are affected by SO_2 concentration.

5. Sorption of Sulfur Dioxide by Typical Indoor Surfaces Including Wool Carpets, Wallpaper, and Paint. M. Walsh, A. Black, A. Morgan, and G. H. Crawshaw. *Atmos. Environ.*, v. 11, No. 11, 1977, pp. 1107-1111. (F77-3)
6. Surface Coatings for Long-Term Protection. J. E. Fowles-Smith. *Bull. Inst. Corrosion Sci. and Tech.*, London, England, No. 66, 1977, pp. 2-6.

Some causes of the premature failure of long-life coatings are discussed, together with the use of paints on galvanized substrates.

7. Technique for the Investigation of Biodeterioration of Paints Developed at CSIRO, Australia. E. Hoffman. J. Oil and Colour Chem. Assoc., v. 60, No. 4, 1977, pp. 121-126.

The author describes the technique for testing a chemical compound for fungicidal activity and determining its persistence in an organic coating under different climatic conditions. When formulations had passed these tests they were subjected to field trials in houses which had a history of mold growth and in a brewery over a bottle washing machine. Paints containing copper 8-hydroxy-quinolate and those containing tetramethyl thiuram disulfide showed good results; zinc oxide was not effective in these field trials nor was N-trichloromethylthiophthalimide as a fungicide. The author lists 4 ways in which fungicide can disappear from a paint film: (1) by reacting with components of the paint or the atmosphere (for example, H_2S), (2) by evaporation if the compound is volatile, (3) by decomposition due to solar radiation, and (4) by leaching out in rain or dew.

8. Weatherability of Acrylic Coatings. R. E. Harren, A. Mercurio, and J. D. Scott. Australian Oil and Colour Chem. Assoc. Proc. and News, v. 14, No. 10, 1977, pp. 17-23.

The influence of polymer or copolymer composition, T_g , vehicle molecular weight, adhesion, polymer heterogeneity, latex particle size, extenders, volume solids, coalescing solvents and oleoresinous modifiers on the durability of acrylic latex paints is discussed and the potential for maximizing the performance of these paints assessed.

9. Vinyl Coatings for Resistance to Atmospheric Corrosion. D. H. Gelfer and K. B. Tator. Mat. Prot., v. 16, No. 12, 1977, pp. 9-13.

The properties of vinyl coatings and their resistance to water, organic and inorganic acids, oxidizing agents, alkalis, salt solutions, solvents, oils, fats and gases are reviewed, together with application data. The precautions for handling these systems are briefly considered.

1976

1. Accelerated Weathering. C. A. Grey. Proc. 2nd Organic Coatings Symp. (1975), Materials Research Laboratories, Australia, Report MRL-R-671, 1976, pp. 11-20.

Comparison of the performance of several paint systems in three enclosed carbon arc artificial weathering instruments with that on natural weathering showed that there was no general correlation. However, with paints of similar type (olive drab alkyd enamels or epoxy/polyamide

paints) comparative ratings by natural and artificial weathering were similar. Performance of some varnishes on wood on natural exposure agreed with that indicated by tensile measurements after artificial weathering.

2. Conservation of Monuments. Proceedings of the 2nd Session of the 29th National Congress of the Assoc. Termotecnica Italiana, Florence (September 25-27, 1974), Antonio Barbieri, Viale Premuda 2, Milano, 1976, 252 pp. (Italian). (OM76-4)
3. Effects of Gaseous Pollutants on Materials: A Chamber Study. F. H. Haynie, J. W. Spence, and J. B. Upham. NTIS Report PB-251580, 1976, 98 pp. (Fe76-5)
4. Effects of pH on the Hardening of Japanese Lacquer Films. T. Kenjo. Science of Conservation, No. 15, March 1976, pp. 1-8 (Japanese).

The effect of several electrolytes on the hardening of Japanese lacquer was studied through infrared spectroscopy. A definite amount of electrolyte was mixed with raw lacquer which, after pH measurement, was applied on a polyethylene sheet to make a lacquer film. The electrolytes tested were NaCl, Na₂CO₃, HCl, H₃PO₄, and (COOH)₂ and the amount of each electrolyte added varied from 0.025 to 2.0 percent. The results are as follows: (1) the ratio of the absorbance at 993 cm⁻¹ to that 985 cm⁻¹ serves as an indicator of hardening. For all the films investigated, it was found that they were in the tack-free state when the ratio was equal to, or above, 12. Therefore, the hardening time has been defined to be the point when the above ratio becomes 12; (2) no significant correlation was observed between the hardening time and the kind of anions added; (3) the pH dependence of hardening was observed. Assuming that the hardening time acceptable for practical use is less than 24 hours, the optimum pH for the hardening of lacquer was found to be from 4.5 to 6.

5. Effects of Power Plant Emissions on Materials. J. E. Yocom and N. Grappone. Research Corporation of New England, Wethersfield, Connecticut, NTIS Report PB-257539, July 1976, 85 pp. (Fe76-6)
6. Effects of Sulfur Dioxide and Acid Precipitation on Metals and Anti-Rust Painted Steel. V. Kucera. Ambio., v.5, No. 5-6, 1976, pp. 243-248. (Fe76-7)
7. Improving Results of Artificial Weathering. E. Preininger and B. Zindy. Proc. 13th FATIPEC Congress, Cannes, 1976, pp. 518-523 (German).

The constancy of the light source is an important factor, as far as reliability of resulting color changes is concerned, in testing the weather fastness of colored paint films. Recently-introduced apparatus makes it possible to examine the behavior of the lamps when in use. In the course of working with 200 6 kilowatt xenon lamps, considerable varia-

tions of light intensity were encountered both initially and during ageing. Weather-fastness tests conducted in a pre-set time period may lead to varied results. It is preferable, as shown by several examples, to conduct tests up to a defined limit of irradiation instead of time. A procedure which has been used for several years in a laboratory equipped with a large number of weather testing machines is described. It is possible to improve significantly the reproducibility of results of accelerated weathering tests. The method allows for comparison of individual apparatus and prevents fluctuations which previously passed unnoticed.

8. Investigation Into a New Method for the Cleaning and Conservation of Medieval Stained Glass Recently Applied in Chartres (France).
J. C. Ferrazzini. CV News Letter, No. 23, December 3, 1976, pp. 4-9.

The article describes drawbacks of a method applied to stained glass at Chartres. The method includes cleaning with ion-selective agents (EDTA) and impregnation of the weathering crust with a two-component resin solution based on an acrylic resin "Viacryl VC 363 (SM 564)" capable of forming polyisocyanate crosslinks upon reaction with "Desmodur N" (aliphatic isocyanate). The protective coating obtained shows excellent weathering resistance, yet its permeability to water and sulfur dioxide appears to be too high to prevent corrosion over a long period of time. However, the use of ion-selective agents can affect the healthy glass and make it susceptible to corrosion. In the author's laboratory a new prophylactic method has been worked out and is now being tested. It will be published shortly.

9. New Developments in Wood Preservatives and Finishes. Deutsche Malerblatt, v. 47, No. 10, 1976, pp. 633-636 (German).

The performance of various types of wood finishes, for example, glazes or pigmented coatings, is discussed. A table summarizes their performance on three types of wood under three artificial weathering cycles.

10. On the Problematics of the Colored Coating of Facades. A. Novak. Památky a Příroda, No. 9, 1976, pp. 530-532 (Czech).

First, the main reasons for the poor adherence of color coating of the plaster on historical buildings is examined (unsaturated old surface, old surface adsorbing the medium of the new film, over-saturation of the medium in the new film). A case is being made for the utilization of frescoed colored surfaces or for immediately preceding saturation of the old plaster with lime water. The pleasing visual effect of radiant color is thus achieved which is superior to the heavy dullness of paints containing white fillers. Except in the adverse situation of a high sulfur content in the air in the industrial areas, the frescoed coating is more economical in terms of amount of pigments utilized and optically more satisfactory.

11. Physical and Economic Damage Functions For Air Pollutants by Receptor. B. Liu and E. Yu. Report No. EPA-600/5-76-011, U.S. Environmental Protection Agency, September 1976, 172 pp. (Fe76-13)
12. Protection Against Atmospheric Corrosion. K. Barton. Translated by J. R. Duncan, Wiley, New York, N.Y., 1976, 194 pp. (Fe76-14)
13. Scientific Analysis and Conservation of Paintings. M. Hours. Office du Livre Fribourg (Suisse), 1976, 128 pp. (French).

Scientific analysis of paintings contributes to the prolongation of life expectancy of major art works through better understanding of the phenomena of change. Information gained through the use of visible light (natural light, and monochromatic sodium), ultraviolet, infrared, and X-ray is detailed. Information furnished by microscopy, chromatography and spectrography carried out at the Research Laboratories of the Museums of France is also listed. Dating methods still in the experimental stage are also given. The scientific analysis also includes study of the influence of the climate, pollution, vibration and lighting.

14. The Microbiological Deterioration of Paints. A. K. Kempson. Australian Oil and Colour Chem. Assoc. Proc. and News, v. 13, No. 2, November 1976, pp. 5-14.

The deterioration of paint by micro-organisms is covered, both "in-can" spoilage and the damage done to paint films. The types of micro-organisms involved, the mechanisms of their actions, and their control are covered.

1975

1. Effects of Gaseous Pollutants on Paints: A Chamber Study. J. W. Spence, F. H. Haynie, and J. B. Upham. J. Paint Technol., v. 47, No. 609, 1975, pp. 57-63.*

A controlled environment chamber study, conducted to statistically identify the significant direct and synergistic effects of 3 air pollutants (SO_2 , NO_2 , and O_3) on oil-base house paint, acrylic latex house paint, vinyl coil coating, and acrylic coil coating, showed that the oil-base house paint experienced the highest erosion rates. The exposure chamber simultaneously controlled temperature, relative humidity, and concentrations of the 3 pollutants, and also featured a dew/light cycle to simulate diurnal conditions. Regression analysis showed that SO_2 concentration and relative humidity accounted for 61 percent of the variability. Vinyl and acrylic coil coatings experienced very low erosion rates, whereas the erosion rates for latex house paint were invalid because SO_2 reacted with the substrate. Neither relative humidity nor temperature had a significant effect on the erosion rate for clean air exposure conditions.

2. Environmental Exposure System for Studying Air Pollution Damage to Materials. J. W. Spence, F. D. Stump, F. H. Haynie, and J. B. Upham. NTIS Report PB-240615, 1975, 46 pp. (Fe75-11)

3. Evaluation of Structural Steel Coatings in Relation to Industrial Atmospheric Conditions. J. C. Moore and J. R. O'Leary. NTIS Report PB-248604/1ST, January 1975, 78 pp.

Project No. 23 has supplied added technical information on the durability of coatings applied to structural steel and exposed to the atmosphere plus chemical fumes from nearby industrial plants. The amount and nature of those chemical fumes were recorded and averaged established for later use in the accelerated testing program. The coating system was designated failing when the degree of rusting of the steel had reached 10% on the ASTM D-610 pictorial standards. Sets of steel panels were blast-cleaned to commercial and to white metal and one set was pre-rusted and then cleaned by wire brushing. Paints were applied by brush and spray. Some one coat primed applied panels were exposed. The general types of available primers and some recommended top coats were included. The most important result of this project is the economy of blast-cleaning the structural steel to at least the Commercial Standard prior to coating. Vinyl top coats show some checking. Aluminum top coats are satisfactory.

4. Medieval Stained Glass Painting. Report on the 9th Colloquium of Corpus Vitrearum in Paris. E. Frodl-Kraft. Oesterr. Zeitschrift fur Kunst und Denkmalpflege, v. 29, No. 3-4, 1975, pp. 154-158 (German).

Administrative problems of the International Corpus Vitrearum are discussed. The conservation methods, especially with the epoxy resin Viacryl, are reviewed in connection with the present condition of the famous glass windows of Chartres cathedral.

5. Prediction of the Corrosion Protective Properties of Paint Films by Permeability Data. H. Haagan and W. Funke. J. of the Oil and Colour Chemists Association, v. 58, No. 10, October 1975, pp. 359-362.

The authors consider the permeability of coatings to water, oxygne, ions, chloride, sulfate, hydroxyl and iron and find that in general the permeability of coatings to water is sufficient to permit corrosion of the substance to occur but the oxygen permeation rate may be lower than that needed for the process of corrosion. The permeability of anions such as chlorides and sulfates is very low, so low that corrosion of the substance by such ions must be due to contamination before the coating was applied, not to duffusion. It is concluded that the behavior of a coating in preventing corrosion might be predicted by measuring the permeability rate for water and oxygen under selected conditions of humidity and temperature.

6. Sulfur Dioxide and Material Damage. D. G. Gillette. J. Air Pollution Control Assn., v. 25, No. 12, December 1975, pp. 1238-1243. (Fe75-17)

1974

1. Accelerated Testing of Durable Coatings. E. Oakley and J. J. Marron. J. Oil and Color Chem. Assoc., v. 57, No. 1, January 1974, pp. 22-29.

This paper presents research into the correlation between various accelerated weathering cycles and conventional weathering tests at Florida, when used to test the durability of high performance acrylic/melanine systems.

2. An Appraisal of Artificial Weathering Methods for Assessment of the Durability of Paint Fibers. C. E. Hoey and H. A. Hipwood. Journal of the Oil and Colour Chemists Association, v. 57, No. 5, May 1974, pp. 151-160.

Comparative tests on paint fibers of different types: air drying alkyd, stored alkyd, epoxy polyamide, polyurethane, epoxy ester, vinyl-toluene, alkyd, chlorinated rubber, oleoresinous, oil-based, storing amino/epoxy and acrylics and emulsion paint exposed to six different types of artificial weathering cycles and the same paints exposed under natural conditions were carried out. The artificial weathering methods were "BS 3900 Part F3," "ASTM E42 Type E," "Dew Cycle," "Xerotest," "Climatest" and "Emmagna apparatus." Exterior durability tests were carried out in the U.K. (temperate climate rural), Australia (tropical wet rural and topical dry rural), Singapore (equatorial wet industrial marine) and U.S.A. (hot dry). The authors give details of the results and compare the different methods of accelerated weathering. They do not conclude that any one cycle is better than another entirely, but explain the particular advantages and disadvantages of each both separately and in comparison with each other.

3. Assessing Air Pollution Damage to Coatings. G. G. Campbell, G. C. Schurr, D. E. Salwikowski, and J. W. Spence. J. Paint Technol., v. 46, No. 593, June 1974, pp. 59-71.**

Common atmospheric pollutants (SO_2 and O_3) exert an adverse effect on the durability of certain exterior organic coatings. Erosion rate studies (supported by, infrared by attenuated total reflectance and by scanning electron microscopy analyses of exposures in a Xe Arc Weather-Ometer and at exterior sites with various levels of pollutants) substantiate this. The Weather-Ometer exposures provide the most direct evidence because those factors that influence erosion rates of exterior coatings (uv radiation intensity, moisture content, and temperature changes) can be controlled. Coatings that contained extender pigments, especially CaCO_3 , showed the greatest effect from SO_2 as a pollutant. Coatings exposed to uv light irradiation showed the greatest effect from O_3 .

4. Colorfastness to Atmospheric Contaminants. V. S. Salvin. Textile Chemist and Colorist, v. 6, No. 7, 1974, pp. 164-166 and No. 8, 1974, pp. 185-189.

Methods for the assessment of the colorfastness of dyes to atmospheric contaminants are reviewed. Colorfastness to oxides of nitrogen, and the chemistry of moist and dry ozone fading are discussed. AATCC test methods are compared with other methods.

5. Design of a Laboratory Experiment to Identify the Effects of Environmental Pollutants on Materials. J. W. Spence and F. H. Haynie. Corrosion in Natural Environments, ASTM American Society for Testing and Materials, STP 558, 1974, pp. 279-291. (Fe74-10)
6. Effect of Air Pollution on Materials and Technical Equipment. D. Knotkova, K. Barton, and B. Dolezel. Ochr. Ovzduš., v. 6, No. 6, June 1974, pp. 75-83 (Czech). (Fe74-12)
7. Pollution Damage to Works of Art. J. Riederer. Chapt. in New Concepts in Air Pollution Research, Birkhauser Verlag, Basel und Stuttgart, 1974, pp. 73-85. (Cu74-5)
8. Science Finds Way to Restore the Art Damage in Florence. D. J. Hamblin. Smithsonian, v. 4, No. 11, 1974, pp. 26-35.

Following the 1966 flood in Florence, Italy, art conservators and scientists gathered to rescue many damaged works of art. Among the treatments developed at that time is a way to reverse the degradation of frescoes in which calcium carbonate has turned into calcium sulfate. The method used to reverse this change involved ammonium carbonate which attacks the gypsum crystals and turns them into CaCO_3 . Conservators defeated microorganisms with Nystatin. Frescoes saturated with water were sealed with tributylphosphate which prevented the frescoes from being washed away as the water evaporated.

9. The Economic Damages of Air Pollution. T. E. Waddell. NTIS Report PB-235701, 1974, 156 pp. (Fe74-21)
10. The Economics of Clean Air In Perspective. F. H. Haynie. Materials Performance and Protection, v. 13, No. 4, April 1974, pp. 33-38. (Fe74-22)

1973

1. Effect of Pigments on the Penetration of Sulfur Dioxide in Coatings. M. Svoboda, B. Knepek, and H. Klicova. J. Oil Colour Chem. Assoc., v. 56, No. 4, 1973, pp. 172-174.

Pigments decreased the sulfur dioxide penetration rate 50-70 percent depending on the type of pigment compared with the penetration rate

through unpigmented lacquer film. Alkyd resin films pigmented with zinc oxide, titanium dioxide, or lead powder and films based on chlorinated rubber pigmented with Pb were used in the tests.

2. Sulfur Reducing Bacteria, Surface Coatings, and Corrosion.
M. E. Williams, R. A. King, and J. D. A. Miller. J. Oil and Colour Chem. Assoc., v. 56, No. 8, August 1973, pp. 363-368.

The way in which sulfate-reducing bacteria cause corrosion of steel is reviewed. A number of biocides were incorporated into a standard coating (polyamide cured pitch-epoxy system) and their effectiveness in preventing bacterial corrosion was measured in simulated conditions. The authors have devised a method of simulating in the laboratory the conditions under which bacterial corrosion occurs, and intend to devise a more rapid method for determining the effect of the bacteria on a protective coating and the actual mechanism of coating failure. Visual examination of the exposed samples was compared with potentiokinetic and potential/time techniques, which appear to be useful in improving knowledge of the fundamental aspects of corrosion of steel.

3. The Damaging Effects of Air Pollution on Works of Art. J. Riederer.
Proc. 3rd Intern Union Air Pollut. Prev. Assoc. - VDI-Komm. Reinhaltung Luft Int. Clean Air Congr. (Duesseldorf, October 8-12, 1973), 1973, pp. A86-A89 (German). (Cu73-3)

1972

1. A Study to Evaluate Techniques of Assessing Air Pollution Damage to Paints. G. C. Campbell, G. C. Schurr, and D. E. Salwikowski. Sherwin-Williams Co., Chicago, Ill., Research Center, Final Report to the U.S. Environmental Protection Agency, EPA-68-02-0030, 1972, 99 pp.

Erosion rate studies supported by attenuated total infrared reflectance measurements and scanning electron microscopy analyses provide a definitive technique for determining the effect of atmospheric pollutants on the performance of exterior coatings. This technique is based on the use of a gas controlled, Xenon Arc type Weather-Ometer. The other methods of testing that were investigated-- tensile strength, gloss or sheen, and surface roughness--provided considerably less consistent trends in data for either the "short term" exterior exposure or the Weather-Ometer studies. Atmospheric pollutants at levels representative of a highly polluted industrial site (1.0 ppm SO₂ or O₃) were shown in Weather-Ometer studies to exert a significant adverse effect on the performance of specific coatings compared to the zero pollutant condition. The ranking of a coating in terms of erosion rates was also shown to be virtually independent of exposure to a pollutant type or level. Four paints were studied--oil house paint, latex and coil coatings, alkyd industrial paint, and automotive refinish.

2. Chemical and Physical Effects of Sulphur Dioxide on Inorganic Pigments and Paints. S. Torlaschi, L. Caggiati, and G. Zorzella. Proc. 11th FATIPEC Congress, Florence, 1972, pp. 207-215.

The behavior of the more important inorganic pigments contained in paints has been studied with regard to an SO₂ atmosphere. This report represents the physical effects and chemical reactions affecting properties such as colour and gloss of paints obtained, in particular, with chrome yellows and chrome molybdate reds. These pigments have proved to be the most sensitive towards the action of SO₂. Appropriate surface treatments, the formulation in paints with other pigments, and the use of certain vehicles have a positive effect on the stability of the paint film.

3. Chemical Attack and Economic Assessment of Air Pollutants on Exterior Paints. J. W. Spence and F. H. Haynie. J. Paint Tech., v. 44, No. 574, 1972, p. 70-74.

This preliminary report investigates the deterioration of exterior paints by sulfur dioxide and particulate matter, and the associated potential economic loss to manufacturers and consumers. Crucial dose-response data are lacking in the published studies surveyed for these pollutants. The potential cost to the consumer due to pollutant attack of four classes of exterior paints is estimated at \$700 million annually, and pollutant damage to household paints represents over 75 percent of that total. A new study involving field and laboratory exposures has been initiated to determine dose-response data from which the economic loss for certain paint classes may be better formulated.

4. Indian Murals. Technique and Conservation. B. Lal. The International Centre for the Preservation and the Restoration of Cultural Property, February 7-16, 1972, pp. 1-19.

Indian wall paintings have suffered extensive damage and deterioration caused by adverse environmental conditions, high temperature, high relative humidity and air pollution. Chemical action of light has also led to drastic changes in colors. A comprehensive survey is given of the condition of Indian murals, their structure, grounds, pigments and binders, and conservation methods which have proved successful.

5. Paint Technology and Air Pollution: A Survey and Economic Assessment. J. W. Spence and F. H. Haynie. NTIS Report PB-210736, February 1972, 49 pp.

The objectives were to survey the technical developments occurring within the paint industry, to identify the characteristics of pollutant attacks on exterior paints, and to estimate the annual cost of air pollutant damage to such paints. New paint formulations and new application techniques are emerging within the paint industry. The chemical attack of certain air pollutants on exterior finishes is

reviewed. An economic assessment was made of the chemical damage of air pollutants on four classes of exterior paints: household, automotive refinishing, coil coating, and maintenance. The total estimated cost at the consumer level is given.

1971

1. Air Pollution by Sulfur Oxides. National Industrial Pollution Control Council, Washington, D.C., Feb. 1971, 27 pp. (Fe71-2)
2. Present Status and Prospects on Air Pollution. U. Bardelli. Ingegneria, v. 5, 1971, pp. 311-316 (Italian). (Fe71-19)
3. Peeling of Paints on Metropolitan Highways. K. Tsuno, M. Shinagawa, and K. Tachikawa. Toso To Toryo, No. 193, 1971, pp. 57-67 (Japanese).

Factors affecting the peeling of paints from the structural steel of the highway system were analyzed by collecting solid materials from the painted surfaces and analyzing for pH, Cl, SO₃, and NO₃ concentration. The data obtained strongly indicate the effect of polluted air on the paint durability, especially in industrial areas.

4. Technical-Economic Evaluation of Air-Pollution Corrosion Costs on Metals in the U.S. F. W. Fink, F. H. Buttner, and W. K. Boyd. NTIS Report PB-198453, February 19, 1971, 160 pp. (Fe71-25)

1970

1. Systems Analysis of the Effects of Air Pollution on Materials. R. L. Salmon. NTIS Report PB-209192, January 15, 1970, 196 pp. (Fe70-13)

1969

1. Corrosion in the Atmosphere. P. Atterby. NTIS Report N71-26259, November 1969, 9 pp. (Fe69-25)
2. Minimum Paint Film Thickness for Economical Protection of Hot-rolled Steel Against Corrosion. J. D. Keane, W. Wettach, and W. Bosch. J. Paint Technology, v. 41, No. 553, 1969, pp. 372-382. (Fe69-33)

3. Protective Coatings for Highway Structural Steels. J. D. Keane. National Cooperative Highway Research Program, Report 74, Highway Research Board, 1969, 64 pp. (Fe69-35)

1968

1. Decay of Plaster, Paintings, and Wall Material of the Interior of Buildings via Microbial Activity. W. E. Krumbein and C. Lange. Chapt. 55 in Biodeterioration of Materials: The Terrestrial Environment, edited by A. H. Walters and E. H. Hueck-Van der Plas, v. 2, Halsted Press Division, John Wiley, New York, N.Y., 1968, pp. 687-697. (MSC68-1)

1967

1. Corrosion by Air Pollution. J. R. Goss. Proc. Annu. Conf., Nat. Soc. Clean Air, No. 34, 1967, pp. 75-92. (Fe67-4)
2. Cost Comparison of Protective Coatings for Steel. C. V. Brouillette, Report R-501, Naval Civil Engineering Laboratory, Port Huememe, CA, November 1967, 9 pp.

Cost of protecting steel in three types of marine atmospheric environments are tabulated for 15 protective coating systems which were shown to have superior protective properties in NCEL Technical Report R-501. The types of environment vary from severe tropical, which contains continuous, wind-blown ocean salt spray to mild subtropical, which contain light intermittent wind-blown ocean salt spray. For the more severe environment, minimum costs of \$0.06 (or less) to \$0.12 per square foot per year of protection are reported.

3. Deterioration of Coated Films of Japanese Lacquer. K. Toishi and T. Kenjo. Shikizai Kyokaishi (Color Material), v. 40, No. 2, 1967, pp. 92-93 (Japanese).

The effects of ultraviolet radiation or increased temperature on Japanese lacquer were studied by infrared spectroscopy. The spectra of 0.01 mm samples which had been irradiated (2,000 lux for 1,116 hours), kept at 80° C or stored in the dark were compared. The alpha-, beta-diketone content of lacquer increased during irradiation while the contents of peroxide, alkyl groups and hydroxy groups decreased. Similar but less marked effects were observed with the lacquer kept at 80° C. These results are attributed to the oxidation of an oil in the lacquer; low molecular weight compounds are also formed, as shown by the decrease in weight of the sample. The color of the lacquer decreased during irradiation.

4. Soiling and Materials-Damage Studies. Chapt. 4 in Economic Costs of Air Pollution. R. G. Ridker. F. A. Praeger, New York, N.Y., 1967, pp. 57-89. (Fe67-7)
5. The Effects of Photochemical Oxidants on Material. L. S. Jaffe. J. Air Pollution Control Association, v. 17, No. 6, 1967, pp. 375-378. (E67-3)
6. The Hot Dip Galvanizing Industry. F. C. Porter. Metallurgia, v. 75, No. 6, 1967, pp. 241-247. (Zn67-4)

1966

1. Hydrogen Sulfide Darkening of Exterior Paint. H. C. Wohlers and M. Felstein. J. Air Pollution Control Association, v. 16, 1966, pp. 619-621.

Hydrogen sulfide reacts with heavy metal salts in exterior paints to form a precipitate which discolors the paint.

1965

1. Art in the Laboratory. M. Richter. Neues Rheinland, No. 47, January 1965, pp. 2-5.

The organization and potentialities for modern restoration, and of the activities of the institutes at Bonn, Cologne and Dusseldorf are surveyed. Attention is given to the special problems for conservation arising from air pollution in the Rhineland-Westphalia region.

2. Atmospheric Corrosion of Painted Steel. A. V. Blom. Korrosion, No. 17, 1965, pp. 58-63.**

The phase range between a metal surface and the paint film, fundamental rusting reactions, and measures to achieve corrosion resistance are reviewed. Rust formation at the interface of the surface and the paint film is caused fundamentally by the potential difference between the surface oxide film and the free metal and by the presence of oxygen and water in the paint film.

Methods of cleaning the metallic surface to be painted to eliminate adsorbed water are summarized. Rusting under the paint is the result of electrolytic reactions made possible by the adsorbed aqueous layer between the surface and the paint film and of purely chemical reactions activated by corrosion accelerators admitted by permeability and porosity of the paint film. Protection against the corrosion of painted metallic surfaces is achieved by inhibition of ion formation by physical or chemical inhibitors in the paint, elimination of water from the critical interface, sealing off of corrosive substances originating in the environment by

2. Influence of Atmospheric Contaminants on Corrosion - Literature Report.
H. C. Muffley. Rock Island Arsenal, Rock Island, Illinois, Report
No. 63-2041, June 13, 1963.

Corrosion preventive coatings are currently designed to prevent moisture from coming in contact with the metal surfaces. Corrosion due to moisture alone is very slow, however, the interaction of moisture and atmospheric contaminants accelerates the rate of corrosion. The fact that moisture and atmospheric contaminants vary independently makes it difficult to predict the corrosion behavior.

3. Performance of Coating on Metal in an Industrial Atmosphere.
V. B. Volkening. 56th Annual Meeting, Air Pollution Control Association, Detroit, Michigan, (June 9-13, 1963), Paper No. 63-86, 1963.

The reason and methods of procedure for a protective coating testing program are discussed. Results based on fifteen years operation of such a program in a chemical plant on the Gulf Coast are described in some detail. Atmospheric contaminants (from high humidity and moisture of condensation to chlorine and hydrochloric acid) were encountered. A method for calibrating the atmosphere is outlined. Differences in the performance of several generic types of coating resins are presented.

4. Scientific Preservative Methods for Cultural Properties. V. Air Pollution. I. Tomokichi. Museum (Tokyo), No. 143, 1963, pp. 28-29 (Japanese).

The effects of smog, dust, and toxic gases like sulfur dioxide are discussed.

5. What Price Maintenance-Free Structures? J. C. Pohlman. Electrical World. v. 159, 1963, pp. 72-74. (Fe63-7)

1962

1. Atmospheric Pollution: Its Measurement and Some Effects on Paints.
G. L. Holbrow. J. Oil and Colour Chem. Assoc., v. 45, 1962, pp. 701-718.

Standard methods of measuring pollution are described. Sulfur dioxide, one of

2. Influence of Atmospheric Contaminants on Corrosion - Literature Report.
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1962

1. Atmospheric Pollution: Its Measurement and Some Effects on Paints.
G. L. Holbrow. J. Oil and Colour Chem. Assoc., v. 45, 1962,
pp. 701-718.

Standard methods of measuring pollution are described. Sulfur dioxide, one of the chief polluting agents, affects only young paint films, chiefly by delaying drying. The concentration of SO₂ in the London area in winter is typically 0.1 to 0.2 ppm by volume. In the smog of December 1952 it reached 1.4 ppm, which can be considered as an upper limit.

2. Scientific Preservation Methods for Cultural Properties. III.
Preservation of Paintings. I. Tomokichi. Museum (Tokyo), No. 141,
1962, pp. 23-25 (Japanese).

Damage by insects and air pollution should be considered in the preservation of paintings. To prevent falling off of pigments, plastic materials like polyvinyl alcohol and acrylic resin were used with good results. Maintenance of paintings after repair is also important.

1961

1. Corrosion In Buildings. P. J. Sereda. Canadian Building Digest, Report No. CBD-20, August 1961, 4 pp. (Fe61-5)

1959

1. Atmospheric Corrosion Tests. J. C. Hudson. Sixth Report of the Corrosion Committee, Iron and Steel Institute, 1959, pp. 48-103. (Fe59-2)
2. Deterioration of Materials in Polluted Atmospheres. J. E. Yocum. Corrosion, v. 15, No. 10, October 1959, pp. 541t-545t. (Fe-5)

1957

1. Automobile Paint Damaged by Airborne Iron Particles. E. G. Fochtman and G. L. Langer. J. Air Pollution Control Assoc., v. 6, 1957, p. 243.

Paint damage in a parking lot located in an industrial region where strong attachment of particles to car finishes has occurred was studied. Results indicate that particles were from a nearby factory. When in contact with the car finish and moisture, the particles formed ferrous hydroxide which penetrated the paint and converted to iron oxide.

1955

1. The Destructive Effects of Air Pollution on Materials. A. Parker. 6th Des Voeux Mem. Lecture, Proc. 22nd Annual Conf., National Smoke Abatement Soc., Bournemouth, England, September 28, 1955, pp. 120-132. (Fe55-6)

1954

1. Deterioration of Materials--Causes and Preventive Techniques.
G. A. Greathouse and C. J. Wessel. Reinhold Publishing, New York, N.Y., 1954, 835 pp. (OM54-1)
2. Paints, Varnishes, Enamals and Lacquers. J. E. Cowling and M. E. Roberts.
Chapt. 10 in Deterioration of Materials--Causes and Preventive Techniques, edited by G. A. Greathouse and C. J. Wessel, Reinhold Publishing Corp., New York, N.Y., 1954, pp. 596-645.

The classifications and components of organic coatings are given. The effect of sunlight, temperature, moisture, dirt, atmospheric conditions and biological organisms on the deterioration of organic coatings is discussed.

3. Selection of Paints and Application In Combating Atmospheric Corrosion.
F. T. Radecke. API Proc., v. 34, Section 3, 1954, pp. 37-49.

Industrial plants incur extensive loss annually because of the ravages of atmospheric corrosion. Metal loss rates vary with severity of environment. The petroleum industry, in particular, can be considered to have serious atmospheric-corrosion problems. The major portion of the refineries (consisting of steel structures and equipment) is constantly under attack from crude-oil components and from treating chemicals in the forms of spills, leaks, and atmospheric effluents. Cooling water-tower condensate, humid climates, and waste materials used as fuels greatly increase the surface-corrosion potential.

The most common method of protection is to apply coatings of paint on exterior steel surfaces. The more important aspects of painting are types of surface preparation, paint selection based on environmental severity, the number of coats to be applied, and dry-film thickness. The best combination of these factors must be determined by the engineer to afford adequate protection within the limits of economic practicability. Shell Oil Company's engineers have established a number of basic coating practices and have developed specification paints for use in the refineries. Improved methods in the field, in conjunction with specification materials, have achieved satisfactory surface protection at reasonable cost.

1953

1. Economic Factors of Atmospheric Corrosion vs. Protection. C. C. Harvey.
API Proceedings, v. 33, Section 3, 1953, pp. 286-290.

Economic appraisal of atmospheric corrosion loss of metal demonstrates that, in most environments, painting is not justifiable solely from the protection standpoint. More economical protection can be provided by the use of an exterior corrosion allowance. However, painting is indicated to be justified when both the decorative and protective

functions are considered. For most large industries the decorative function of paint plays a more important role in maintaining good employee and community relations than is normally recognized.

Graphic analysis of long-term paint economics indicates that maintenance of coatings in their best condition usually costs less than allowing them to deteriorate before repainting. On-site atmospheric corrosion data and careful analyses of painting practices are recommended as maintenance dollar savers.

1952

1. Economics of Industrial Maintenance Painting. R. R. Pierce. Corrosion, v. 8, 1952, pp. 178-182.*

Over 60% of the established industrial maintenance paint compositions will fail rapidly when used for maintenance in a chem.-industrial atmosphere. Surface preparation by blasting will increase the protective life of the maintenance paint system from 2 to 4 times over that applied to wire-brushed, corroded surfaces. Maintenance paint system thicknesses below 5 mils are undependable in aggressive chem.-industrial atmospheres. Regular schedules of paint inspection and repair can reduce cost of plant protection to about 5¢ per sq. ft. per year even in aggressive chem.-industrial atms.

2. Key to Savings in Painting Costs. R. R. Pierce. Chem. Eng., v. 59, No. 5, 1952, pp. 149-153.*

A comprehensive evaluation of costs for protective coatings in industrial plants is presented. It is concluded that a three-coat painting system resulting in a 5-mil minimum total thickness gives the most economical required corrosion protection.

1951

1. Fading of a Dye Cellulose Acetate by Light and Gas Fumes. M. Couper. Text. Res. J., v. 21, 1951, pp. 720-725.

Cellulose acetate fabric was exposed to nitrogen oxides to determine the chemical reactions which occur during dye fading.

1939

1. Effect of Sulfur Compounds in the Air on Various Materials. L. R. Burdick and J. F. Barkley. U.S. Bureau of Mines, I.C. 7064, April 1939, 9 pp. (Fe39-1)

PLASTICS

1982

1. Atmospheric Corrosion Testing in Norway. L. Atteraaas and S. Haagenrud. Atmospheric Corrosion, edited by W.H. Ailor, Wiley, New York, N.Y., 1982, pp. 873-892. (Fe82-20).
2. Measurement of the Time-of-Wetness by Moisture Sensors and Their Calibration. P. J. Sereda, S. G. Croll and H. F. Slade. Atmospheric Corrosion of Metals, edited by S. W. Dean, Jr., and E. C. Rhea, American Society for Testing and Materials, ASTM STP 767, 1982, pp. 267-285. (Fe82-42)

1981

1. Organic Matrix Structural Composites: Quality Assurance and Reproducibility. Committee on Characterization of Organic Matrix Composites. Report No. NMAB-365, National Materials Advisory Board, 1981, 156 pp.

The use of organic matrix advanced composites as primary (system critical) structures has increased rapidly. As a consequence of this rapid growth there has not been the opportunity to develop either the broad experience or technology base to use these composites with the same degree of confidence as with metallic alloys.

The first objective of this study was to survey and assess the state of the art of organic matrix structural composites technology. The second goal was to formulate a set of recommendations to:

- (1) Assure by prior specification that fabricated structures will meet performance requirements;
- (2) Predict lifetime behavior through analysis and accelerated test methods for ultra-violet and gamma radiation, ozone, oxygen, solvents, temperature, moisture, and sustained loading; and
- (3) Provide verification methods for both, thus assuring product specification and early indication of failure.

1980

1. A Review of Air Pollutant Damage to Materials. J. E. Yocum and A. R. Stankunas. Draft Report to Environmental Criteria and Assessment Office, Office of Research and Development, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, December 1980, 92 pp. (Fe80-2)

2. Accelerated Weathering Tests for Glass-Fiber Reinforced Polyester (GRP) Sheets. R. S. Yamasaki and A. Blaga. Durability of Building Materials and Components, ASTM STP 691, edited by P. J. Sereda and G. G. Litvan, American Society for Testing and Materials, 1980, pp. 874-889.

With the development of GRP's of improved durability to weathering it has become necessary to devise accelerated weathering tests that permit assessment of their performance and durability within a reasonable time. The new artificial weathering procedure subjects GRP materials to a cycle of 2 hour xenon arc radiation (twice the intensity used in the previously reported cycle of 4 hour radiation and 4 hour cold water spray) and 0.67 hour cold water spray. Exposure of fire-retardant, non-gel-coated, and conventional GRP sheets induced surface degradation similar to that produced by both the 4-4 cycle and outdoor exposure in a considerably shorter time. The acceleration rate was 2.0 to 3.5 (compared with the 4-4 cycle) and 5 to 30 (compared with outdoors).

3. An Assessment of the Degradation Effects of South African Weather Conditions on Organic Building Materials. R. E. Cromarty, H. W. Ahrens, G. S. Van Eeden and B. Zahradnik. Durability of Building Materials and Components, ASTM STP 691, edited by J. Sereda and G. G. Litvan, American Society for Testing and Materials, 1980, pp 890-903.

The variations in outdoor weather conditions in Southern Africa are related to the geography of the country and the influence of these different conditions on organic materials is discussed. The visual changes in a series of organic building materials that have been exposed to different climates for 6 years are recorded and commented on without attempting to elucidate the mechanism of degradation. The physical changes that occur as a result of exposure in polychloroprene rubber sheets, that originally conformed to standard specifications, are detailed and discussed. The effectiveness of various ultraviolet absorbers on the rate of degradation of polypropylene under conditions of natural and accelerated artificial exposure is discussed. The overall suitability of organic building materials for use under South African conditions are discussed and recommendations are made.

4. Appraisal of Durability of Organic Materials and Components--The Australian View. K. G. Martin.* Durability of Building Materials and Components, ASTM STP 691, edited by P. J. Sereda and G. G. Litvan, American Society for Testing and Materials, 1980, pp. 106-118.

The performance concept is used as a basis for discussing the limitations of artificial "weather" chambers as devices to assess the durability of organic building materials. Problems of prediction are shown to be inherent owing to the relations between the climatic factors and the rate processes involved in most weathering degradation. The increased use of outdoors exposure testing is advocated with attention to specimen type, whether commercial product or prototype, and the use of results whether for compliance or guide for design as expounded in Australian Standards.

A new quantitative description of climate as it relates to photo-oxidation of organic building materials is described in terms of a "solar weathering index" for use in research and development. The role of simple quality control tests, as complimentary to outdoors exposure tests, is outlined. The results with a simple ultraviolet lamp test are reported and proposals for a simple chalking test are described.

5. Background and Principles of Long-Term Performance of Building Materials. S. E. Pihlajavaara. Durability of Building Materials and Components, ASTM STP 691, edited by P. J. Sereda and G. G. Litvan, American Society for Testing and Materials, 1980, pp. 5-16. (Fe80-4)
6. Deterioration Mechanisms in Weathering of Plastic Materials. A. Blaga. Durability of Building Materials and Components, ASTM STP 691, edited by P. J. Sereda and G. G. Litvan, American Society for Testing and Materials, 1980, pp. 827-837.

Deterioration of most plastic materials starts at the outer surface and may take the form of discoloration, pitting, exudation of ingredients, fiber prominence, and microcracking. The deleterious effects of weathering consist of a complex set of processes in which the combined action of ultraviolet (UV) light and oxygen are predominant. When the energy of an excited group or segment of a molecule cannot be released through a photophysical process, it causes the dissociation of a chemical bond to produce free radicals. This event, with or without the participation of oxygen, can lead subsequently to one or more chemical changes. Light-initiated degradation makes the plastic more susceptible to fracture by stress fatigue induced by changes in humidity and temperature; the resulting surface microcracks cause a loss in mechanical properties. Fiber prominence can be produced by stress fatigue alone, but its formation is accelerated by UV irradiation.

7. Development of Testing Techniques for Aging Plastics in Buildings Due to Natural and Artificial Weathering. H. Pfeifer. Durability of Building Materials and Components, ASTM STP 691, edited by P. J. Sereda and G. G. Litvan, American Society for Testing and Materials, 1980, pp. 863-873.

The characteristics of plastics, compared with the time-dependent classical building materials, may be subjected to considerably greater changes due to weathering. These have defied exact specification so far and are a decisive handicap in their use.

The report gives a critical review of the development of test methods for the determination of natural and artificial weatherings and formulates suggestions for generally acceptable testing methods. Weathering and test methods are proposed that provide for the use of plastics in building constructions.

8. Durability Studies on Polymer Materials Used Externally in Building.
P. Eurin, R. Cope, J. C. Marechal and G. Roux. Durability of Building Materials and Components, ASTM STP 691, edited by P. J. Sereda and G. G. Litvan, American Society for Testing and Materials, 1980, pp. 838-852.

There is evidence that no one form of artificial weathering test will make it possible to forecast with accuracy the durability of all the polymer materials used externally in building. Methods that take account of the mechanism of degradation of individual materials are required. Glass-fiber reinforced polyesters (GRP) break down by weakening of the bond between the glass-fibers and the resin. An indication of durability can be obtained from measurements of the modulus of dynamic torsion before and after degradation in boiling water and the comparison of these results with the results for other GRPs of known durability. The durability of opaque rigid poly(vinyl chloride) (PVC) depends on the presence of a thermal stabilizer to inhibit a chain reaction characterized by the elimination of hydrogen chloride and the formation of conjugated double bonds. This process is accompanied by progressive embrittlement. A dehydrochlorination (DHC) test enables the minimum life of a PVC material to be estimated. It seems probable that a constant-speed perforation test, used in conjunction with the DHC test, will improve the estimates of durability for these materials.

9. Effects of TiO_2 on the Weatherability of Thermoplastic Polymers.
G. Irick, J. S. Zannucci, J. C. Ownby and R. H. S. Wang. Durability of Building Materials and Components, ASTM 691, edited by P. J. Sereda and G. G. Litvan, American Society for Testing and Materials, 1980, pp. 853-862.

Titanium dioxide is used widely as an opacifying agent for paper, fibers, coatings, and plastics. Our data show that this white pigment functions as either a weathering stabilizer or sensitizer, depending on its concentration or treatment during manufacture and use. Lifetimes of oxidizable polymers, such as polypropylene, and cellulose esters, can be reduced greatly by the presence of photoactive titanium dioxides; oxidation-resistant polymers, such as poly(tetramethylene terephthalate), are affected to a much lesser extent. The undesirable effects of titanium dioxides can be reduced greatly by the presence of certain additives. The large effects of temperature on the lifetimes of certain polymers indicate that considerable care must be exercised in the design of accelerated test methods.

10. Exponential Aging of Certain Plastics. F. R. Landi. Durability of Building Materials and Components, ASTM STP 691, edited by P. J. Sereda and G. G. Litvan, American Society for Testing and Materials, 1980, pp. 904-909.

Natural aging tests suffer greatly from the long time period required for completion; testing time is of the same order of magnitude as the lifetime. Correlation of the results of the natural aging test with that of the accelerated test is difficult. With certain materials, such as plastics and organic coatings, some progress has been made. Plastics,

when exposed to ultraviolet radiation or when irradiated and heated, undergo a deterioration process which can be described by the exponential relation of the type $E = E_0 \cdot e(-\gamma t)$. It appears to be possible to establish performance criteria of aging from the parameters of the exponential term which depend on the nature and shape of the material tested. Also, for the decay caused by other factors, for example, change in temperature and humidity, the same relationship may be applicable.

11. Some Aspects of the Durability of Plastics in Building. J. R. Crowder. Durability of Building Materials and Components, ASTM STP 691, edited by P. J. Sereda and G. G. Litvan, American Society for Testing and Materials, 1980, pp. 811-826.

The requirements for durability of building products is discussed with particular reference to plastics. The processes of deterioration are considered as well as their significance in relation to performance. Methods of following change must be realistic in relation to use, and the factors involved are discussed, notably UV radiation as the basis of laboratory assessment procedures. There is need for better understanding of deterioration to aid in total appraisal of building products.

1979

1. Glovebox Glove Deterioration in the Hanford Engineering Development Laboratory Fuel Fabrication Facility. W. O. Greenhalgh, R. C. Smith, and D. L. Powell. NTIS Report PC-A03/MF-A01, July 1979, 44 pp. (E79-2)

1978

1. Notes on the Development of Damages in Materials. H. H. Kausch and G. G. Amoroso. *Materiaux et Techniques*, No. 3, March 1978, pp. 79-84 (French).

The mechanical and chemical damages found in compound materials of polymer and stone are described.

2. Reaction of Polymers With Pollutant Gases. H. H. G. Jellinek. *Aspects Degradation Stab. Polym.*, Elsevier, Amsterdam, 1978, pp. 431-499.

Reactions of polymers with pollutant gases are reviewed.

3. The Effect of the Polluted Urban Atmosphere on Degradation of Polymers. F. Flajsman. *Chem., Kunstst.-Aktuell* (1977), 1978, pp. 21-23. (E78-1)

1977

1. Natural Aging of Plastic Materials Used in the Construction Industry.
L. Rechner. Cashiers Centre Sci. Tech. Batiment, No. 181, 1977, 48 pp.
(French).

Results are given of a comprehensive study involving the natural exposure of the fifteen main classes of plastics materials at several sites of different climatic environment in France for a period of ten years. Changes in color, gloss and occurrence of film degradation (cracking, etc.) are recorded. An aging profile has been constructed for each class of plastics material.

2. Photo-Oxidative Degradation of Polymer Coatings. P. L. Zubov and E. A. Kanevskaya. DAN SSSR, v. 233, No. 1, 1977, pp. 148-151 (Russian).

A detailed study was made of light aging processes in polymeric coatings (copolymers of butyl methacrylate with 5 percent methacrylic acid on an aluminum foil substrate) with particular reference to the effect of internal stresses on these processes. The light aging performance can be improved by reducing the internal stresses.

1976

1. Effects of Gaseous Pollutants on Materials: A Chamber Study.
F. H. Haynie, J. W. Spence, and J. B. Upham. NTIS Report PB-251580, 1976, 98 pp. (Fe76-5)
2. Effects of Power Plant Emissions on Materials. J. E. Yocom and N. Grappone. Research Corporation of New England, Wethersfield, Connecticut, NTIS Report PB-257539, July 1976, 85 pp. (Fe76-6)
3. Physical and Economic Damage Functions for Air Pollutants by Receptor.
B. Liu and E. S. Yu. Report No. EPA-600/5-76-011, U.S. Environmental Protection Agency, September 1976, 172 pp. (Fe76-13)
4. Protecting Electronics From Atmospheric Corrosion. D. V. Couden.
Materials Engineering, May 1976, pp. 22-25. (Cu76-7)
5. Protection Against Atmospheric Corrosion. K. Barton. Translated by J. R. Duncan, Wiley, New York, N.Y., 1976, 194 pp. (Fe76-14)
6. Protection of Stained-Glass Windows Against Atmospheric Agents. Study of Synthetic Resin Films. J. M. Bettembourg. Verres Refract., v. 30, No. 1, 1976, pp. 87-91 (French).

Epoxy and polyurethane resins for the protection of ancient stained-glass windows were assessed. The glass was washed with Na_2EDTA and NaHCO_3 , and then thin films of Viacryl VC 363 + Desmodur N75, Neocolle DE 874, or Araldite AY epoxy 103 + HY 956 were applied. Atmospheric weathering agents included UV light and SO_2 . Weathering caused a yellowing and diminished transparency of glass coated with Necolle, but had no effect on the Viacryl + Desmodur-coated glass. Weathering also diminished the adherence of Araldite to the glass.

7. Study of the Effect of Some Climatic Factors on the Aging of Polystyrene. B. Dolezel and L. Adamirova. Donaulaendergesprach, 9th, v. 2, 1976, pp. 194-203 (German).*

Photo-oxidative weathering degradation of polystyrene is retarded by humidity and accelerated by NO_2 . Sulfur dioxide also inhibits photodegradation and diminishes the catalytic effect of NO_2 .

1975

1. Environmental Exposure System for Studying Air Pollution Damage to Materials. J. W. Spence, F. D. Stump, F. H. Haynie and J. B. Upham, NTIS Report PB-240615/5ST, January 1975, 46 pp. (Fe75-11)
2. The Effects of Nitrogen Oxides on Plastics. H. Huber and F. Goerg. Staub-Reinhalt Luft, v. 35, No. 5, 1975, pp. 184-187 (German).

Tensile tests and scanning electron microscope examination of 35 μm thick polyamide and polyester fibers, 35 μm thick polyamide film containing 5 percent of low pressure polyethylene, 40 μm thick polyethylene-terephthalate film containing 2 percent of polypropylene, and 90 μm thick polyethylene-terephthalate film containing 5 percent of low pressure polyethylene, after exposure to 100 ppm of nitrogen oxides for 17 to 48 days, showed considerable deterioration of the polyamide and hardly any change in the polyester. Changes in the polyamide could have been caused by depolymerization, change of electrical forces between adjacent molecules, and reactions of oligomers.

1974

1. Degradation of Polymers at Low Temperatures by Nitrogen Dioxide, Ozone, and Near-UV Radiation. H. H. G. Jellinek. NTIS Report AD-782950/OGA, 1974, 31 pp.**

A tensile strength, and a static and a dynamic stiffness tester have been constructed for measuring mechanical properties of polymers as a function of temperature, environmental conditions (that is, air plus NO_2 , O_3 , etc. or the pollutants alone), exposure time, and pollutant

concentration. The dynamic stiffness tester is especially sensitive to onset of cracking due to O_3 . Tensile strength of linear polyurethane was affected by NO_2 alone and also by NO_2 in the presence of air. Chain scission, cross-linking, evolution of CO_2 and other low molecular weight compounds, and formation of nitro and nitroso groups along the polymer backbone occurred. Preliminary selection of polymeric skirting materials for surface effect vehicles was made on the basis of results as functions of temperature.

2. Design of a Laboratory Experiment to Identify the Effects of Environmental Pollutants on Materials. J. W. Spence and F. H. Haynie. Corrosion in Natural Environments, ASTM STP 558, American Society for Testing and Materials, 1974, pp. 279-291. (Fe74-10)
3. Effect of Air Pollutants on Aging of Plastic Materials: Protection Methods. J. Verdu. Trib. CEBEDEAU, v. 27, No. 369-370, August-September 1974, pp. 360-365 (French).*

Air pollutants accelerate the aging of plastic materials by direct reaction, by the formation of photochemical active species which accelerated chain oxidation, and by intervention in the polymer degradation mechanism. Ozone reacted with the double bonds to cause degradation. Sulfur dioxide formed photochemical active species and increased the cleavage rate in polymer chains. Known methods of chemical and physical stabilization were not always effective against the aging effects of atmospheric pollutants.

4. Effect of Air Pollution on Materials and Technical Equipment. D. Knotkova, K. Barton, and B. Dolezel. Ochr. Ovzduš., v. 6, No. 6, June 1974, pp. 75-83 (Czech). (Fe74-12)
5. Effect of Oxidative Components of Air Pollutants on the Degradation of Polymers. F. Flajsman. Kem. Ind., v. 23, No. 2, 1974, pp. 96-100 (Croatian). (E74-3)
6. The Economic Damages of Air Pollution. T. E. Waddell. NTIS Report PB-235701, 1974, 156 pp. (Fe74-21)
7. The Use of Weather and Climatological Data in Evaluating the Durability of Building Components and Materials. L. W. Masters and W. C. Wolfe. NTIS Report COM-74-50841/7, August 1974, 102 pp. (Fe74-25)

1973

1. Concentrations, Decay Rates, and Removal of Ozone and Their Relation to Establishing Clean Indoor Air. R. H. Sabersky, D. A. Sinema, and

F. H. Shair. Environ. Sci. Technol., v. 7, No. 4, 1973, pp. 347-353.
(OM73-2)

2. Effect of Sulfur Dioxide on the Chemical and Physical Properties of Nylon 66. S. H. Zeronian. Textile Research Journal, v. 43, No. 4, 1973, pp. 228-237.

The degradation of nylon 66 fabrics by exposure to light and air is increased if the air is contaminated with sulfur dioxide. The effect of degradation by light and air contaminated with sulfur dioxide (0.2 ppm), by hydrolysis with sulfuric acid, or by irradiation with light in the presence of sulfuric acid on the surface of nylon fibers and on the thermal behavior of nylon was examined and the mode of degradation is discussed.

1971

1. Chain Scission of Butyl Rubber by Nitrogen Dioxide. II. Photo-oxidation as a Function of Nitrogen Dioxide, Oxygen Pressure, and Temperature. H. H. G. Jellinek and P. Hrdlovic. J. Polymer Sci., Part A-1, v. 9, No. 5, 1971, pp. 1219-33.**

The degradation mechanism of butyl rubber was studied as a function of temperature, pressure of oxygen and nitrogen dioxide, and the effect of near UV radiation. NO_2 retarded chain scission in the presence of near UV light. Arrhenius equations for the photooxidation mechanism are discussed.

2. Degradation of Polymers and Morphology: Photo-oxidative Degradation of Isotactic Polystyrene in the Presence of Sulfur Dioxide as a Function of Crystallinity. P. Hrdlovic, J. Pavlinec, and H. H. G. Jellinek. J. Polymer Sci., Part A-1, v. 9, No. 5, 1971, pp. 1235-45.**

In a study of the photooxidative degradation of polystyrene (isotactic) films (prepared in a variety of ways producing different degrees of crystallinity) in the presence of SO_2 and NO_2 , pronounced effects of crystallinity on the rates of degradation were observed. In the presence of SO_2 , the rate of chain scission increased with the extent of crystallinity and was assumed to be faster due to strain in and near the folds in the crystalline areas. In the presence of NO_2 , chain scission increased up to 8% crystallinity but then became constant. The diffusion rates of oxygen and NO_2 into the films decreased with increasing crystallinity. The diffusion and chain scission rates compensated each other after an 8% degree of crystallinity was reached.

1970

1. Chain Scission of Polymers by Small Concentrations (1 to 5 ppm) of Sulfur Dioxide and Nitrogen Dioxide, Respectively, in the Presence of Air and

Near Ultraviolet Radiation. H. H. G. Jellinek. J. Air Pollut. Contr. Assoc., v. 20, No. 10, 1970, pp. 672-674.**

The extent of chain scission (crosslinking) suffered by various polymers exposed to 1 atm air and near UV light ($\lambda > 2800 \text{ \AA}$) in the presence and absence of nitrogen dioxide, sulfur dioxide, and ozone, respectively, at 1 to 5 ppm was determined. Vinyl polymers are scarcely affected by SO_2 and NO_2 , respectively; however, nylon and elastomers are quite sensitive toward these gases. These conclusions agree with observations, found in the literature, on tensile tests, elongations, flexibilities and ir measurements in the presence of sulfur dioxide under similar conditions.

2. Effect of Ozone on the Strength of a Polystyrene Film. S. A. Abasov, M. A. Bagirov, T. I. Guseinov, and U. A. Kabulov. Izv. Akad. Nauk Azerb. SSR, Ser. Fiz.-Tekh. Mat. Nauk, No. 4, 1970, pp. 57-61 (Russian).

The ozonization of polystyrene films showed that, depending on the ozonization time, the strength and durability of the polystyrene initially increased, then decreased, and finally, slowly increased during ozone treatment. The changes observed were attributed to crosslinking, degradation, and oxidation.

3. Photolytic Oxidation of Isotactic Polystyrene in the Presence of Sulfur Dioxide. I. Chain Scission as a Function of Temperature at Constant Oxygen and Sulfur Dioxide Pressures and Constant Light Intensity. H. H. G. Jellinek and F. J. Kryman. Proc. Symp. Photochem Macromol. (1969), edited by R. F. Reinisch, Plenum, New York, N.Y., 1970, pp. 85-90.*

The reaction of polystyrene (isotactic) in SO_2 and O_2 at constant light intensity, studied as a function of temperature showed that SO_2 was essential for effecting or enhancing chain scission in near UV light. The polymer film was exposed to constant SO_2 (0.85 mm Hg) and O_2 (15 cm Hg) in UV light ($\lambda > 2800 \text{ \AA}$) at temperatures from 30 to 57°. The chains suffered random scission according to a random mechanism and the energy of activation for a combination of secondary reactions was 4.5 kcal/mole.

4. Photolytic Oxidation of Isotactic Polystyrene in the Presence of Sulfur Dioxide. II. Photolysis Reaction as a Function of Light Intensity, and Sulfur Dioxide, and Oxygen Pressure. H. H. G. Jellinek and J. Pavlinec. Proc. Symp. Photochem. Macromol. (1969), edited by R. F. Reinisch, Plenum, New York, N.Y., 1970, pp. 91-104.*

The chain scission reaction of polystyrene (isotactic) in SO_2 and O_2 and near UV radiation ($\lambda > 2800 \text{ \AA}$) as a function of gas pressure and light intensity allowed the formulation of a mechanism for the photolysis reaction based on a type of Bollard mechanism for oxidative degradation degradation in conjunction with the pronounced synergistic action of SO_2 . This reaction was accounted for by a mechanism where chain scission proceeded via the formation of hydroperoxide groups. The ratio of chain

scission quantum yields (ϕ) (number of chain scissions/number of quanta absorbed) due to SO_2 and O_2 , respectively, was very large, i.e., $\phi\text{SO}_2\phi\text{O}_2 = 143$. This clearly shows the great effect SO_2 has, even at low pressure, on this chain scission reaction.

5. Systems Analysis of the Effects of Air Pollution on Materials.
R. L. Salmon. NTIS Report PB-209192, January 15, 1970, 196 pp.
(Fe70-13)
6. The Weathering and Performance of Building Materials. J. W. Simpson and P. J. Horrobin, eds., Medical and Technical Publishing Co. Ltd., 1970, 277 pp. (Fe70-17)

1969

1. Combined Effects of Deformation and Ozone on Molecular Bond Rupture in Rubber. L. K. De Vries, E. R. Simonson, and M. L. Williams. Polym. Prepr., Amer. Chem. Soc., Div. Polym. Chem., v. 10, No. 2, 1969 pp. 1190-1197. (E69-1)
2. Reaction of Nitrogen Dioxide with Polystyrene Films. H. H. G. Jellinek and F. Flajsman. J. Polymer Sci., Part A-1, v. 7, No. 4, 1969, pp. 1153-1168.*

The reaction of NO_2 with thin polystyrene films was investigated at 35° with different partial pressures of NO_2 (0.1, 2, 15, 30, and 60 cm. Hg) and at several temps. (25, 35, 45 and 55°). The films were thin enough (approx. 20 μm) so that the reaction was independent of the diffusion of gas into the polymer. The experimental results can be represented by a chain mechanism. The whole degradation process is controlled by the diffusion of polymer radicals out of cages. This diffusion, in turn, is affected by the decrease in viscosity or decrease in weight-average molecular weight as degradation proceeds. This leads to an acceleration of the degradation process. A straight-line relation between the logarithm of the reciprocal weight-average molecular weight and the logarithm of a reaction-time function was found. The dependence on the rate was substantiated by degrading polymer fractions. The energy of activation for the process is small, in agreement with a diffusion process for chain scission. Nitro and nitrite groups are incorporated along the backbone of polystyrene during exposure. The number of these polar side groups appears to pass through a maximum with time, as is evidenced by aggregation of polymer molecules in benzene solution only during the middle stage of the degradation. The final stage of the process is slowed down by a retarder being produced. This retarder can be removed by reprecipitation of exposed polymer films. Degradation in solution is similar to that of films. Isotactic polystyrene shows less irregularity in its degradation curve than the atactic polymer. This is, presumably, due to its more homogeneous morphology, large molecular weight, and broader molecular size distribution. The plot of the degree

of degradation versus time for the isotactic polymer can be satisfactorily approximated by a straight line.

3. Reaction of Sulfur Dioxide and Nitrogen Dioxide with Polymers.
H. H. G. Jellinek, F. Flajsman and F. J. Kryman. J. Appl. Polymer Sci., v. 13, No. 1, 1969, pp. 107-116.*

Polymers were exposed to SO_2 , nitrous oxide and to mixtures of these with oxygen under ultraviolet irradiation. All polymers suffered some deterioration (chain scission and/or crosslinking), and the deterioration was considerable with exposure over long periods of time. Elastomers were more susceptible to these gases than saturated polymers, but the effects were not quite so drastic as those caused by O_3 . The polymers studied included: polyethylene, polypropylene, polystyrene, poly (Me methacrylate), poly(vinyl chloride), polyacrylonitrile, nylon, polybutadiene, butyl rubber, and polyisoprene.

1967

1. Fundamental Degradation Processes Relevant to Outdoor Exposure of Polymers. H. H. G. Jellinek. Applied Polymer Symposia, No. 4, 1967, pp. 41-59. (E67-2)

1965

1. Stability of Some Plastics in Corrosive Media. N. A. Kolesnik, O. A. Fridman, I. M. Brods'ka, and A. A. Degtyar'ova. Khim. Prom., Inform. Nauk-Tekhn. Zb., v. 2, 1965, pp. 11-14 (Ukrain).

Moldings from glass-reinforced plastic AG-4C, copolymer MSN, polycaprolactam, and polyethylene were treated with inorganic acids and bases and organic solvents. Changes in mechanical properties and weight of the moldings were evaluated. H_2SO_4 , HCl , HNO_3 , NH_3 , and NaOH as aqueous solutions, and acetone, benzene, dichloroethane, CCl_4 , PhCl , and cyclohexane were used as liquids at room temperature; HCl , HNO_3 , NH_3 , acetone, CCl_4 , PhCl were used as gases at 30 to 60° C.

2. Fading of Coloring Matters. C. H. Giles. J. Appl. Chem., v. 15, No. 12, 1965, pp. 541-550. (F65-1)

1961

1. Effect of Nitrogen Tetroxide on Metals and Plastics. C. W. Alley, A. W. Hayford, and H. F. Scott, Jr. Corrosion, v. 17, No. 10, October 1961, pp. 479t-484t. (Fe61-6)

1958

1. Relation Between Actual and Artificial Weathering of Organic Materials. F. M. Reinhart. Symposium of Some Approaches to Durability in Structures, American Society for Testing and Materials, ASTM STP 236, 1958, pp. 57-66.

Laboratory tests can be controlled fairly well. However, outdoor exposure tests are at the mercy of the weather. The temperature, relative humidity, sunshine, and rain vary not only from one geographical location to another but also at the same location from month to month and from year to year. These variations are of sufficient magnitude so that actual outdoor exposure tests made in one particular year and in only one or two localities cannot be considered as a standard for rating the performance of laboratory simulated (artificial) weathering tests. Outdoor exposure tests intended for evaluating the reliability of artificial weathering tests should be made over several years in several localities.

1956

1. Weathering of Plastics. J. J. Gouza and W. F. Bartoe. Modern Plastics, v. 33, No. 9, May 1956, pp. 157-158, 160, 162, 244-245.

The procedures for studying surface deterioration, crazing, and creep deformation of plastics subjected to stress during outdoor exposure are discussed. Considered are critical creep strain, threshold crazing stress, permanent set, and predicted service life. The data show the possibility of failure of test results obtained in laboratory atmospheres to predict outdoor service characteristics.

1954

1. Deterioration of Materials - Causes and Preventive Techniques. G. A. Greathouse and C. J. Wessel. Reinhold Publishing, New York, N.Y., 1954, 835 pp. (OM54-1)
2. Three Years' Outdoor Weather Aging of Plastics Under Various Climatological Conditions. S. E. Yustein, R. R. Winans and H. J. Stark. ASTM Bulletin No. 196, 1954, pp. 29-38.

The effects of outdoor weather aging under widely different climates are investigated for various types of plastic materials. Five climatological regions are represented in the program which provides for outdoor exposures on sites located in (1) Panama Canal Zone (tropical); (2) New Mexico (dry desert); (3) New York (temperate); (4) Fort Churchill, Canada (subarctic); and (5) Point Barrow, Alaska (arctic). The materials investigated include five types of clear transparent sheet plastics, six types of laminated materials, and five types of molded terminal bars. Various

exposure periods from 1 to 36 months were employed, and various mechanical, electrical, and optical properties were evaluated. On the basis of the extensive data accumulated, it is possible to deduce the occurrence of a wide variety of effects that appear to be related to differences in the climatic and environmental conditions and in the exposure periods.

1951

1. Deterioration of Organic Polymers. B. S. Riggs. Bell System Tech. J., v. 30, 1951, pp. 1078-1101; Bell Telephone System Tech. Pubs., Monograph No. 1913, 1951, 25 pp. (E51-3)

1950

1. The Influence of Ozone on Paint Vehicles and Some Macromolecular Products. F. J. Hermann, H. W. Talen, and G. J. Scheffer. Central Inst. Materiaal Onderzoek Afdel. Verf, Circ. No. 68, 1950, 25 pp. (E50-1)

OTHER NONMETALS

1981

1. Organic Matrix Structural Composites: Quality Assurance and Reproducibility. Committee on Characterization of Organic Matrix Composites. Report No. NMAB-365 National Materials Advisory Board, 1981, 156 pp. (P8-1)

1980

1. A Review of Air Pollutant Damage to Materials. J. E. Yocum and A. R. Stankunas. Draft Report to Environmental Criteria and Assessment Office, Office of Research and Development, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, December 1980, 92 pp. (Fe80-2)
2. Background and Principles of Long-Term Performance of Building Materials. S. E. Pihlajavaara. Durability of Building Materials and Components, ASTM STP 691, edited by P. J. Sereda and G. G. Litvan, American Society for Testing and Materials, 1980, pp. 5-16. (Fe80-4)
3. Corrosion of Metal in Wood Products. A. J. Baker. Durability of Building Materials and Components, ASTM STP 691, edited by P. J. Sereda and G. G. Litvan, American Society for Testing and Materials, 1980, pp. 981-993. (Fe80-7)
4. Critical Review of the Available Physico-Chemical Material Damage Functions of Air Pollution. M. Benarie. Report No. EUR-6643, Commission on the European Communities, 1980, 97 pp. (Fe80-8)
5. Design Determines Durability. G. K. Garden. Durability of Building Materials and Components, ASTM STP 691, edited by P. J. Sereda and G. G. Litvan, American Society for Testing and Materials, 1980, pp. 31-37. (MSC80-8)
6. Durability of Materials and Construction. J. H. Keyser. Durability of Building Materials and Components, ASTM STP 691, edited by P. J. Sereda and G. G. Litvan, American Society for Testing and Materials, 1980, pp. 38-55. (Fe80-9)
7. Durability of Some Common Building Materials. W. H. Gutt and L. H. Everett. Durability of Building Materials and Components, ASTM

STP 691, edited by P. J. Sereda and G. G. Litvan, American Society for Testing and Materials, 1980, pp. 131-144. (Fe80-10)

8. Durability of Structural Particleboard Evaluated by Repetitive Loading Tests. M. Okuma, T. H. Lin, and S. Onuki. Durability of Building Materials and Components, ASTM STP 691, edited by P. J. Sereda and G. G. Litvan, American Society for Testing and Materials, 1980, pp. 935-945.

A new test method was developed to evaluate the durability of particleboard - a repetitive bending test on air dried and wetted specimen. The durability of three types of particleboard (phenolic, urea-melamin and urea resin bonded board) was discussed by (a) number of the mechanical cycles until failure, (b) increase in deflection with cycles, and (c) residual strength at various stages of mechanical cycles.

It was recognized that the effect of moisture was most critical for urea and urea-melamin board. The superiority of phenolic board came in evidence by this repetitive loading test. From the results of this fatigue test, it also was attempted to derive "degradation coefficient" for allowable stress of particleboard.

9. Effect of Accelerated Aging on Tensile Perpendicular-to-Glueline Strength of Glue-Laminated Beams. M. D. Sandoe, F. J. Keenan, F. C. Beall and S. P. Fox. Durability of Building Materials and Components, ASTM STP 691, edited by P. J. Sereda and G. G. Litvan, American Society for Testing and Materials, 1980, pp. 924-934.

Several glued-laminated beams of both conventional and "hot-press" manufacture were removed from service and exposed to several cycles of alternating high (85 percent) and low (35 percent) relative humidities at 50°C in an attempt to predict long-term durability of the gluebonds. Residual glueline strength, as measured by a flexural specimen loaded to induce tensile stress perpendicular to the glueline, was more variable and significantly lower for hot-press material. Residual strength of hot-press gluebonds varied with longitudinal position in the beam, with minimum strengths found in the region where maximum bending under in-service loads occurred. The tension perpendicular-to-glueline flexure specimen is suggested as a more sensitive indicator of gluebond integrity than the standard shear-block specimen.

10. Effects of a Cold Dip Treatment on Natural Durability of Wood-Base Building Materials Against Decay and Dimensional Change. R. Chow and J. W. Gerdemann. Durability of Building Materials and Components, ASTM STP 691, edited by P. J. Sereda and G. G. Litvan, American Society for Testing and Materials, 1980, pp. 959-971.

A standard ASTM method was used for evaluation of decay resistance and dimensional durability on 13 commercial wood-base building materials. Both treated and untreated specimens were exposed in decay chambers to *Lenzites trabea* and *Poria monticola* for 16 weeks. The results of the average decay resistance of untreated specimens indicate the importance of

wood species and board composition rather than board type. All treated specimens exhibited excellent decay resistance and dimensional stability. However, the preservative treatment failed to retard the thickness swelling of particleboards. Phenol-formaldehyde bonded particleboards were dimensionally stabler than urea-bonded particleboards in the decay chamber. Due to the inherent absorbability, specimens of fiberboards, particle boards, and plywoods appear to be more suitable for cold-dip treatment than those of lumber to protect from decay. However the decay resistance, dimensional changes, and absorption of solution all depend on the wood species, fiber structure, adhesives, panel construction, and specific gravity that made up the wood-base materials.

11. Precision of Rate Process Method for Predicting Durability of Adhesive Bonds. M. A. Millett, R. H. Gillespie and A. J. Baker. Durability of Building Materials and Components, ASTM STP 691, edited by P. J. Sereda and G. G. Litvan, American Society for Testing and Materials, 1980, pp. 913-923.

The influence of such experimental variables as time, temperature, adhesive type, specimen heterogeneity, and moisture conditions on life-expectancy forecasts was explored under two environmental moisture extremes-dry and water-soaked. The data indicated that there could be a rather broad error band associated with these projections. Use of the lower 95 percent confidence limits, however, provides a positive means for estimating minimum bondline durabilities. With proper attention to experiment design, the rate-process method can provide durability forecasts will within the needs of most applications. Maximum sensitivity is attained under wet aging conditions.

12. Prelaid Particleboard Flooring in New Zealand. J. I. Fry and R. S. Whitney. Durability of Building Materials and Components, ASTM STP 691, edited by P. J. Sereda and G. G. Litvan, American Society for Testing and Materials, 1980, pp. 946-958.

The prelaying of urea formaldehyde particleboard floors, as a working platform before the erection of the walls, has been practiced in New Zealand for the past 12 years. Approximately 80 percent of all new houses are constructed in this manner. Little is published about the extent of deterioration of particleboard that occurs during the exposure to the weather before houses are closed in. This paper reports the results of changes in physical and mechanical properties of particleboard exposed to the weather for periods of up to 6 months. The changes were measured both before and after the particleboard had been sanded back to a clean surface. After 3 months weathering and subsequent sanding, the particleboard tested met standard criteria for bending strength. Lack of a suitable surface for clear finishing may determine the amount of weathering the flooring can be subjected to before the houses are closed in.

1979

1. A Study of the Weathering Behavior of Medieval Glass From York Minster. G. A. Cox, O. S. Heavens, R. G. Newton, and A. M. Pollard. *Journal of Glass Studies*, v. 21, 1979, pp. 54-75.

Two hundred glass specimens were analyzed by X-ray fluorescence. Surface corrosion is slight in those samples containing over 60 mol percent silica. Crusting and pitting in various degrees is evident when the silica content is less. Those containing over 6 mol percent magnesia are greatly deteriorated.

2. Fundamentals of Glass Weathering Problems. L. L. Hench and D. E. Clark. *Reliability of Materials for Solar Energy: Workshop Proceedings, CONF-781228*, v. 2, Pt. 2, October 1979, pp. 251-265.

The primary emphasis of this study is on weathering of high durability glass compositions. Some composition-dependent results are presented that should be generally applicable to understanding and preventing deterioration of specialty and historical glasses. The experiments described show that the mechanism of weathering is a near-surface process and is strongly influenced by glass composition, percent relative humidity, temperature, surface treatments, geometric effects such as orientation and distance of separation of glass surfaces, and affinity of the glass surface for water.

3. Use of Building Surfaces in the Passive Abatement of Gaseous Air Pollutants. H. S. Judeikis. *Journal of Architectural Research*, v. 7, No. 1, March 1979, pp. 28-33. (Fe79-10)

1978

1. Deteriorative Effect of Sulfur Pollution on Materials. J. O. Nriagu. Chapt. 1 in *Sulfur in the Environment, Part II: Ecological Impacts*, edited by J. O. Nriagu, Wiley, New York, N.Y., 1978, pp. 1-59. (Fe78-11)

2. Effects of Oxygen-Containing Sulfur Compounds on Organic Materials. H. Ross. *VDI-Ber.*, v. 314, 1978, pp. 109-118 (German).

The detrimental effects of atmospheric sulfur dioxide on textiles, plastics, wood and leather are reviewed.

3. Effects of Weathering on Impregnated Charcoal Performance. Research Annual Report, October 1, 1976-September 30, 1977, edited by V. R. Deitz, Naval Research Laboratory, Washington, D.C., NTIS Report PB-278536, February 1978, 68 pp.

The use of activated and impregnated charcoals by the nuclear industry for periods of 2 to 3 years without regeneration is an adsorbent application with new and undefined maintenance problems. These relate to the effect of atmospheric contaminants on the useful life of the charcoal. There is a need for the nuclear industry to know which air pollutants degrade the efficiency of charcoals and the long-range influence of these pollutants. Commercial activated charcoals have been exposed to known contaminants under controlled laboratory conditions and also to large volumes of outdoor air; each sample was then evaluated for methyl iodide penetration. The laboratory air mixtures studied were water vapor, water vapor and sulfur dioxide, water vapor and ozone, and water vapor and carbon monoxide. The charcoal in each of the four 0.5-inch layers making up the two-inch test bed was degraded by the contaminants, but the first layer was influenced most. The cumulative effect during 1, 2, and 3 months of weathering the same charcoal with out-door air led to a progressive increase in methyl iodide penetration.

4. The 12th Century Stained Glass. I. W. Thompson. *Environment*, v. 20, No. 3, April 1978, p. 24.

The 18th century stained glass of Canterbury Cathedral in London is being steadily eroded by acids in polluted air. According to I. W. Thompson, the dean of Canterbury, as reported in the *Washington Post* (2/3/79), "The deterioration of much of the early glass is far advanced and it will take all the resources of scientific skill and equipment to save it." A glass workshop has been set up inside the cathedral area to store and treat the most endangered glass.

1977

1. Chartres: Through a Glass Darkly. *Time*, January 31, 1977, pp. 54-55.

The stained-glass windows of the Chartres Cathedral, having been submitted to natural damage for years were restored in 1976 and given a protective coating of Viacryl resin. This has caused an avalanche of protests because the resin has destroyed the optical effect of the glass; moreover, a physicist claims that the resin renders the glass twice as susceptible to renewed corrosion and he has done tests which suggest that the resin is not impermeable to molecules of water and sulfur dioxide. The restorers have replied that Viacryl was perfectly safe and so the restoration project will continue.

2. Deterioration in Leather Bookbindings--Our Present State of Knowledge. B. M. Haines. *British Library Journal*, v. 3, No. 1, Spring 1977, pp. 59-70.

This investigation was prompted by the realization (made as early as 1850) that old leather bookbindings deteriorate less quickly than new bindings. The author compares the pre-1850 binding techniques with those used after 1850, from the tanning process to the dangers of air pollution.

The mechanism of decay is discussed, and the effects of sulfur dioxide, acid conditions, and oxidation considered.

3. Effects of the Environment. G. Thomson. Conservation in Australia, 1977, pp. 46-53. (OM77-2)
4. Effects of Sulfur Dioxide on Materials. S. K. Gajendragadkar. Chem. Age India, v. 28, No. 8, August 1977, pp. 673-677. (Fe77-5)
5. Effects on Economic Materials and Structures. J. E. Yocum and J. B. Upham. Chapt. 2 in Air Pollution, edited by A. C. Stern, Academic Press, New York, N.Y., v. 2, 1977, pp. 65-116. (Fe77-6)
6. Nitrogen Oxides. National Research Council Staff Environmental Effects Research Series, Contract EPA-68-02-1226, National Research Council, Washington, D.C., February 1977, 503 pp. (OM77-6)
7. Pollution and the Deterioration of Materials. S. H. H. Chaston. Conservation in Australia, 1977, pp. 54-59. (OM77-7)
8. Rapid Weathering of Wood and Paintings Under the Additional Influence of Sulfur Dioxide. A. Uwe and G. Uwe. Staub Reinhalt Luft, v. 37, No. 2, February 1977, pp. 53-55 (German). (Pa77-3)
9. Relation Between Mass Wear of Organic Protective Coatings and Meteorological Data. W. D. Kaiser. Korrosion (Dresden), v. 8, No. 1, 1977, pp. 3-15 (German). (Pa77-4)
10. Sorption of Sulfur Dioxide by Typical Indoor Surfaces Including Wool Carpets, Wallpaper, and Paint. M. Walsh, A. Black, A. Morgan, and G. H. Crawshaw. Atmos. Environ., v. 11, No. 11, 1977, pp. 1107-1111. (Pa77-5)

1976

1. Air Pollution and Aspects of Polymer Degradation. I. Cook. ICCM Bulletin, v. 2, No. 4, December 1976, pp. 4-20. (E76-1)
2. Air Pollutants and Possible Effects on Artistic and Archaeological Materials. F. Guidobaldi. Conservazione dei Monumenti, 1976, pp. 14-48 (Italian). (OM76-2)

3. Air Pollution Damage Functions. A. Hershaft. Environmental Science and Technology, v. 10, No. 10, October 1976, pp. 992-995. (Zn76-1)

4. An Improved Method for Vacuum Consolidation of Decayed Stone Sculpture. K. F. B. Hampel. 2nd International Symposium on the Deterioration of Building Stone, Athens, 1976, pp. 163-166.

The author discusses impregnation of stone sculpture with a "silane monomer," apparently Rhône-Poulenc X54-802. Eight centimeters is reported to be the maximum depth of penetration achieved by brush application, but with the use of the Balvac vacuum process it is reported to be 15-30 centimeters for marble and 2.5 centimeters for dense limestone. The control of polymerization afforded by isolation from atmospheric humidity is said to eliminate shiny surface patches. Use of the undiluted product is possible. As a result, it is said that longer time before polymerization affects greater absorption and that excess resin can be re-used, making the process economical. The new method is illustrated with photographs of the treatment of a Veronese limestone sculpture (14th century). A modification of the process is described for use on very weak stone.

5. Colorfastness to Light and Atmospheric Contaminants. J. E. Hemphill, J. E. Norton, O. A. Ofjord and R. L. Stone. Text. Chem. Color., v. 8, No. 4, 1976, pp. 60-62. (F76-2)

6. Composition and Weathering of Ancient Stained Glass Windows. J. M. Bettembourg. Verres Refract., v. 30, No. 1, 1976, pp. 36-42 (French).

Stained glass windows from the Middle Ages were studied with respect to composition in relation to atmospheric weathering.

7. Conservation Of Monuments. Proceedings of the 2nd Session of the 29th National Congress of the Assoc. Termotecnica Italiana, Florence (September 25-27, 1974), Antonio Barbieri, Viale Premuda 2, Milano, 1976, 252 pp. (Italian). (OM76-4)

8. Effects of Gaseous Pollutants on Materials: A Chamber Study. F. H. Haynie, J. W. Spence, and J. B. Upham. NTIS Report PB-251580, 1976, 98 pp. (Fe76-5)

9. Effects of Power Plant Emissions on Materials. J. E. Yocom and N. Grappone. Research Corporation of New England, Wethersfield, Connecticut, NTIS Report PB-257539, July 1976, 85 pp. (Fe76-6)

10. Further Progress in German Stone Conservation. J. Riederer. Chapter in The Conservation of Stone I, edited by R. Rossi-Manaresi, 1976, pp. 369-374.

In this report for the years 1972-1975, the use of "ethyl silicates" for stone consolidation is said to have increased to 38% of all treatments (193 total) in Germany, accompanied by a decrease in the use of soluble silicates and synthetic polymers. "Ethyl silicate" is said to penetrate "ordinary" sandstone about 4 centimeters.

11. Laboratory Measurement of Sulfur Dioxide Deposition Velocities on Selected Building Materials and Soils. H. S. Judeikis and T. B. Stewart. Atmos. Environ., v. 10, No. 9, 1976, pp. 769-776. (MSC76-29)
12. Manufacturing and Environmental Factors Affecting the Permanence of Paper. A. J. Watson. Archives and Manuscripts, v. 6, No. 7, August 1976, pp. 285-291.

A general article covers the major aspects of the composition of papers, modern paper manufacture, environmental factors affecting the permanence of paper (light, temperature, humidity, atmospheric pollutants and handling), the testing of papers, and major works in the literature of paper testing.

13. Measurement of the Effects of Air Pollution on Paper Documents. W. H. Langwell. J. of the Society of Archivists, v. 5, No. 6, October 1976, pp. 372-373.

The process of paper deterioration caused by sulfur dioxide is reviewed and a description is given of a simple test using strips of filter paper impregnated with dark brown colloidal manganese dioxide which become bleached in the presence of atmospheric sulfur dioxide. The rate of bleaching is proportional to the amount of sulfur dioxide to which the strips are exposed.

14. Measurements of Air Pollution Effects on Lumber in the Framework of an Effects-Monitoring System for the Ruhr Area. U. Arndt and U. Gross. Staub - Reinhalt. Luft, v. 36, No. 10, October 1976, pp. 405-410 (German).

Unprotected lumber samples were exposed at 42 sites in the western Ruhr area in the period May-November 1972, and at 37 sites in the eastern Ruhr area a year later. The weight loss per gram of original weight and changes in reflection and color of the wood were chosen as effects criteria. After six months of exposure, all wood pieces showed remarkable changes which could be traced to air pollution effects. The main effect was by sedimenting dust which changed the "normal" weight loss and the color, and thus the aesthetic value of the wood. The influence of the dust was so strong that any effects of gaseous pollutants, such as sulfur dioxide, were not detectable. Thus the question of the effects of sulfur dioxide, in concentrations found in polluted areas, remains open.

15. Microprobe Investigations on the Incrusted as Well as Cleaned Marble Specimens. E. Hoke. Proc. 2nd International Symposium on the Deterioration of Building Stones, Athens, 1976, pp. 119-126. (MSC76-30)
16. Outdoor Weathering: Its Objectives and Limits. F. Rosendahl. Proc. 13th FATIPEC Congress, Cannes, France, 1976, pp. 563-567 (German). (OM76-13)
17. Protection Against Atmospheric Corrosion. K. Barton. Translated by J. R. Duncan. J. Wiley, New York, N.Y., 1976, 194 pp. (Fe76-14)
18. Protection by Cleaning and Conservation. J. Riederer. Das Gebäudereiniger-Handwerk, No. 2, 1976, pp. 14-15 (German). (OM76-18)
19. Protection of Stained-Glass Windows Against Atmospheric Agents. J. M. Bettembourg. Verres Refract., v. 30, No. 1, 1976, pp. 87-91 (French).

Epoxy and polyurethane resins for the protection of ancient stained-glass windows were assessed. The glass was washed with Na_2EDTA and NaHCO_3 and then thin films of Viacryl VC 363 plus Desmodur N75, Neocolle DE 874, or Araldite AY epoxy 103 plus HY 956 were applied; atmospheric weathering agents included ultra-violet light and SO_2 . Weathering caused a yellowing and diminished transparency of glass coated with Neocolle, but had no effect on Viacryl plus Desmodur-coated glass. Weathering diminished the adherence of Araldite to the glass.

20. Reactions of Lignin and Lignin Model Compounds With Ozone. K. Kratzl, P. Claus, and G. Reichel. TAPPI, v. 59, No. 11, November 1976, pp. 86-87.

An investigation was made of the reactions resulting from treatment of Kraft lignin and lignin model compounds with ozone. Ozonolysis of aromatic compounds usually results in ring opening and formation of carboxyl groups. While destruction of lignin chromophores occurs during oxidation, because of the specificity of the reaction of lignin with ozone, the conclusion is drawn that less damage occurs to the lignin macrostructure during ozonolysis than during oxygen bleaching processes.

21. Scanning Electron Microscope Studies on the Corrosion of Medieval and Roman Glasses. G. Nauer, E. Kny, and H. Sorantin. Ber. Oesterr. Studienges. Atomenerg., SGAE BER No. 2646, 1976, 17 pp. (German).

The composition and distribution of elements were investigated for ancient and medieval sodium and potassium glasses. Correlations between corrosion and distribution of trace elements were indicated by X-ray spectra. For all glasses, calcium and potassium content decreased in the corrosion layer as iron and manganese increased. These studies are also

useful in the restoration and conservation of old glass, such as stained glass windows.

22. The Conservation of Tandu. D. J. Vandyke-Lee. *Studies in Conservation*, v. 21, No. 2, 1976, pp. 74-78.

Collections of ethnographical leatherwork from West Africa contain many different utility objects. There is one group which is not strictly leather and is made from the stomach membrane of camels and parts of cow skin. These articles made by the Hausa people of Northern Nigeria are known as "Tandu". Vessels are made by molding the wet membrane around a shaped, air-dried clay mold. On drying, the clay is removed to leave a strong but light utility vessel or container. There are many reasons for the deterioration of the Tandu vessels; these include damage by mold or fungi due to unsuitable temperatures and relative humidities, ultra-violet light and strong illumination that produce fading and eventual break-down of the protein, insect attack, and air pollution. Remedies for these problems are suggested, together with the practical treatment in a laboratory.

23. The Effect of Corrosion on the Decomposition Rate of Glass from the Middle Ages. J. C. Ferrazzini. *Verres Refract.*, v. 30, No. 1, 1976, pp. 26-29 (French).

The effect of corrosion on the speed of decomposition of blue stained glass from the 14th century A.D. was discussed.

24. The Treatment of Deteriorating Stone with Synthetic Resins. A. Monclief. *Proc. 2nd International Symposium on the Deterioration of Building Stone*, Athens, 1976, pp. 167-169.

Satisfactory results of exposure testing of X54-802 (Rhône-Poulenc) and other alkoxysilanes are reported. An interesting test method used on deteriorated Portland limestone at St. Paul's Cathedral is only described in this article: line grids were inscribed to a depth of 1 mm on a horizontal and vertical surface of each stone; after three years the grids on the horizontal surfaces of the controls were totally obliterated and nearly obliterated on the vertical surfaces, while the impregnated samples remained unchanged. The author notes that an insufficient percentage of solids seems to be a problem for most "silicon ester" consolidants other than the X54-802; hence, they are said to be ineffective on very deteriorated stone. This is attributed to the fact that they do not cure fast enough to yield a good concentration in the stone, much of the consolidant being lost through evaporation. Strengthener H (Wacker) is said to produce good results on very deteriorated marble, but only after time-consuming application.

For filling X54-802-consolidated stone, the author rules out the use of other synthetic resins as binders, because they display poor adhesion to (or weather differently from) the consolidated stone. In the case of Carrara marble, Doultong stone, and red Verona, the author reports that the filler is too flat or dark when the original stone is ground for use

as the aggregate. It is suggested that flatness may be ameliorated by the use of large particles of white glass or quartz; success is reported with hand grinding quartz, avoiding the use of steel mills which may contribute undesirable iron particles. Putties made with X54-802 are said to be difficult to use because the material must be allowed to partially cure to achieve a usable (higher) viscosity, and the working time is short. Furthermore, when silica is mixed with X54-802, the fills are said to be very hard and difficult to rub down, especially after complete polymerization. Curing problems are noted with the use of very finely ground aggregates. Bubbles formed during mixing are said to cause problems after weathering because the voids tend to trap dirt and water. To avoid this, use of a range of aggregate sizes for tight packing is suggested, or application of the fills prior to consolidation of the stone, so that the voids are filled during consolidation. The author mentions promising experimentation with a commercial substance (unnamed), consisting of solid silicone dissolved in "silane" to produce a liquid of medium viscosity, and with a water-repellent used for stone.

1975

1. Air Pollution and Possible Effects on Archaeological Objects Buried in the Ground. B. Ottar and S. E. Haagenrud. Conservation in Archaeology and the Applied Arts, IIC, Stockholm Congress, 1975, pp. 199-206. (OM75-1)
2. Analysis of Weathered Glass From York Minster. R. G. Newton and R. E. M. Hedges. Archaeometry, v. 16, Pt. 2, 1975, pp. 244-245.

Analysis was made of the cleaned surface of eight pieces of glass from a late twelfth-century panel from York Minster. Samples were also taken from one piece of green glass and one piece of pink glass for wet chemical analysis. Differences in the resistance to weathering of the pink and green glasses were attributed to variations in the proportions of potassium and calcium.

3. Conservation--The Regional Climatic and Natural Conditions. O. P. Agrawal. Museum, v. 27, No. 4, 1975, pp. 161-165. (OM75-3)
4. Environmental Exposure System for Studying Air Pollution Damage to Materials. J.W. Spence, F.D. Stumps, F.H. Haynie and J.B. Upham. NTIS Report PB240615/5ST, January 1975, 46 pp. (Fe75-11)
5. Environmental Protection of Books and Related Materials. Second Preservation Leaflet, Library of Congress, Washington, D.C., 1975, 4 pp.

This leaflet is an outline/summary of environmental causes, and prevention, of deterioration in paper. There are paragraphs on temperature and humidity, mold, atmospheric pollutants, light, insects and

rodents. An appendix lists sources of hygrothermographs and thermohygrometers, and acid-free mounting and matting board.

6. Keeping a Cathedral Alive. K. Spence. Country Life, v. 158, No. 4070, July 3, 1975, pp. 6-8.

This article describes the restoration work being done in the walls and windows of Canterbury Cathedral. The Caen stone walls, consisting of two stone skins with a filling of rubble in between, have been adversely affected by weathering on the outside--rain, frost, and fumes--and by the heating system and the effluvia of thousands of visitors on the inside. The stonework is being cleaned and, where necessary, replaced with Lepine stone. The stained glass windows have also been affected by the environment. The restoration process includes removing the windows and transporting them in 2 by 4 foot panels to a studio. Here the lead is removed, melted down, and extruded. Each piece of glass is cleaned first by ultrasonics for 6 minutes in a bath of ammonia and water, by which the worst encrustations are removed. Using an airbrasive and glass beads, the scale is cleaned out of the surface pits in the glass. Finally, the glass is acid polished to complete the cleaning process and bring out the color. Broken pieces of glass are stuck together with epoxy resin. Any piece of glass that is in too bad a condition is backed with a new piece of glass which is molded to it. Any inpainting that has to be done is done on the backing glass.

7. Medieval Stained Glass. Corrosion-Conservation-Restoration. E. Frobl-Kraft. Conservation in Archaeology and the Applied Arts, Stockholm Congress, Part IIc, 1975, pp. 105-110.

The chemistry of weathering and corrosion of stained glass is considered. Protective methods are compared and methods of repair are discussed.

8. Medieval Stained Glass Painting. Report on the 9th Colloquium of Corpus Vitrearum in Paris. E. Frodl-Kraft. Oesterr. Zeitschrift fur Kunst und Denkmalpflege, v. 29, No. 3-4, 1975, pp. 154-158 (German).

Administrative problems of the International Corpus Vitrearum are discussed. The conservation methods, especially with the epoxy resin Viacryl, are reviewed in connection with the present condition of the famous glass windows of Chartres Cathedral.

9. Reaction Mechanism of Corrosion of Medieval Glass. J. C. Ferrazzini. Conservation in Archaeology and the Applied Arts, Stockholm Congress, Part IIc, 1975, p. 135.

Variations from manufacturing methods are discussed, as are other factors which make a glass susceptible to corrosion. The actual mechanisms of corrosion are then considered.

10. Sulfates and the Environment-A Review. R. S. Greeley, R. P. Ouellette, J. T. Stone and S. Wilcox. Mitre Corporation, McLean, Virginia, Report No. MTR-6895, March 1975, 155 pp. (OM75-8)
11. Sulfur Dioxide and Material Damage. D.G. Gillette. J. Air Pollut. Control Assoc., v. 25, No. 12, December 1975, pp. 1238-1243. (Fe 75-17)
12. The Weathering of Medieval Window Glass. R. G. Newton. J. of Glass Studies, v. 17, 1975, pp. 161-168.

Chemical analyses of glass fragments found together in a single burial deposit showed that durability is enhanced by a sufficiently high silica content and an optimum total proportion of lime and magnesia. A simulated medieval glass of poor durability was prepared and subjected to various kinds of exposure. Atmospheres of various kinds are less destructive than burial in the ground. Contrary to the opinion of many, atmospheric sulfur dioxide is not an important cause of the deterioration of medieval stained glass windows.

1974

1. Cathedral Chemistry: Conserving the Stained Glass. R. G. Newton. Chemistry in Britain, v. 10, No. 3, March 1974, pp. 89-91.

Early medieval glass in Britain, especially that at Canterbury and at York, is a potash glass which is high in alkali (18 per cent) and lime (20 per cent). This type of glass deteriorates in a moist atmosphere because it has a relatively low silica content (55 per cent or less by weight) and too much lime. Not only is it hydrolysed by moisture but the decomposition products form opaque crusts. Thus, the way to reduce deterioration is to wash the windows regularly, thereby removing the alkali carbonates, or to exclude water completely.

Our understanding of the way glass has deteriorated through the centuries is growing, but so far the only methods for halting the damage are (i) the laminating procedure, as used at Cologne Cathedral and (ii) the isothermal glazing system, which is known to be satisfactory when used in heated buildings. But much more research is needed before proper advice can be given to those who have the task of looking after these ancient glass treasures.

2. Design of a Laboratory Experiment to Identify the Effects of Environmental Pollutants on Materials. J. W. Spence and F. H. Haynie. Corrosion in Natural Environments, ASTM STP 558, American Society for Testing and Materials, 1974, pp. 279-291. (Fe74-10)
3. Environment and Quality of Life. Literature Study on the Economic Consequences of the Damages and Annoyances Both in Materials and Vegetation and in Men and Animals Caused by Sulfur Dioxide Air

Pollution. E. Lahmann. Commission of the European Communities, Luxemborg, September 1974, 150 pp. (German). (Fe74-16)

4. Long-Term Air Pollution Effects on Unprotected Lumber. U. Arndt and U. Gross. Staub-Reinhalt. Luft, v. 34, No. 6, June 1974, pp. 225-227 (German).

Long-term air pollution effects on unprotected lumber were studied over a one-year period in four different locations in the North Rhine-Westphalia region. Four types of wood samples were examined after an exposure of one year for weight and color modifications as well as for accumulations of pollutant elements such as sulfur and lead. Pollutant fallout rates were measured over a forty-day period for dust, sulfur dioxide, and fluorine. The exposure changed the color, luster, and weight of the wood samples, which greatly lowered their aesthetic value, but the technical and physical properties were not changed so strongly.

5. Petroleum and the Environment, Rome - EUR (April 11-14). Poligrafico Artioli Editore, Modena, Italy, 1974. (OM74-10)
6. Problems Arising from the Weathering of Poorly-Durable Glasses. R. G. Newton. 10th Intern. Congress Glass, Ceramic Soc. Japan, Tokyo, Japan, v. 9, 1974, pp. 49-54.**

Protective methods for the poorly durable glass in medieval windows from weathering were given. Resin coatings like Vycoat ACA 60, Acrylek, Bedacryl 122X, Bedacryl 123 AH, and SC28 were found unsatisfactory for long-term protection of poorly durable glass.

7. Remarks on Forms of Corrosion and Conservation Work on Medieval Stained-Glass Paintings. E. Frodl-Kraft. Oesterr. Zeitschrift fur Kunst und Denkmalpflege, v. 28, No. 4, 1974, pp. 200-209 (German).

The corrosion of a stained glass window at Kremsmunster, Upper-Austria, could be documented in situ within the last 30 years. The appearance of the painting was destroyed by air pollution. Documentation is given for the last 10 years of alteration of other important stained-glass windows of medieval origin in Austria (Judenburg, St. Walpurgis, Kreuzenstein) and the results of protection by a double window are shown.

8. The Deterioration and Conservation of Painted Glass: A Critical Bibliography and Three Research Papers. R. G. Newton. Oxford University Press, New York, 1974, 93 pp.

The contents include: bibliography, recovery of lost or faded decoration on painted glass; a study on cleaning painted and enamelled glass in an ultrasonic bath; and use of the "isoprobe" for studying the chemical composition of some 12th-century glass from York Minster. A fairly comprehensive coverage of the most important papers in the

literature concerned with the conservation of painted glass is given. The detailed introduction is in itself and overview of the subject.

9. The Economic Damages of Air Pollution. T. E. Waddell. NTIS Report PB-235701, 1974, 156 pp. (Fe74-21)
10. The Environment and Collections. G. W. Rogers. Canadian Conservation Institute Newsletter, No. 4, August 1974, pp. 5-6. (OM74-15)
11. The Environment and Collections (Part 2). G. W. Rogers. Canadian Conservation Institute Newsletter, No. 5, November 1974, pp. 2-3. (OM74-16)

1973

1. Bibliography of Studies on the Deterioration and Conservation of Stained Glass. R. G. Newton. Art Arch. Tech. Abst., v. 10, No. 2, 1973, pp. 132-178.

This bibliography attempts to cover most of the important papers in the literature which have a bearing on the conservation of painted glass. Subjects covered include the deterioration of painted glass, cleaning of painted glass, restoration, consolidation and chemical analyses of medieval glasses.

2. Concentrations, Decay Rates, and Removal of Ozone and Their Relation to Establishing Clean Indoor Air. R. H. Sabersky, D. A. Sinema, and F. H. Shair. Environ. Sci. Technol., v. 7, No. 4, 1973, pp. 347-353. (OM73-2)
3. Investigation of Damages (On Cultural Properties) Caused by Air Pollution. T. Kadokura. Science for Conservation, No. 11, 1973, pp. 69-85 (Japanese). (OM73-5)
4. Recent Evidence of Decomposition of Stained Glass of the Middle Ages. G. Frenzel. Proc. 3rd Int. Union Air Pollut. Prev. Assoc.-VDI-Komm. Reinhaltung Luft Int. Clean Air Congr. (Duesseldorf, October 8-12, 1973), 1973, pp. A82-A85 (German).

The processes by which carbon dioxide, sulfur dioxide, and sulfuric acid have accelerated the weathering of these stained glass windows are discussed, including the effect of glass composition.

5. The Damaging Effects of Air Pollution on Works of Art. J. Riederer. Proc. 3rd Intern. Union Air Pollut. Prev. Assoc.-VDI-Komm.

Reinhaltung Luft Int. Clean Air Congr. (Duesseldorf, October 8-12, 1973), 1973, pp. A86-A89 (German). (Cu73-3)

1972

1. Deterioration of Library Materials. C. J. Wessel. Encyclopedia of Library and Information Science, Marcel Dekker, New York, v. 7, 1972, pp. 69-120.

Historical and economic factors in the increasing rate of deterioration of library materials are discussed, along with some proposed national plans for controlling deterioration. Permanence and durability are defined, and fundamental mechanisms of the deterioration of materials are presented. Environmental factors, including pollutants, temperature and humidity, light and biological agents are discussed, along with the interrelationships of these factors. The role of inherent instability in book and photographic materials is emphasized. Finally, environmental parameters for minimizing deterioration, taken from the literature, are recommended.

2. Sorption of Sulfur Dioxide by Indoor Surfaces--IV. Flooring Materials. D. J. Spedding. J. Appl. Chem. Biotechnol., v. 22, No. 1, 1972, pp. 1-8.

The sorption of SO_2 by a number of carpet and solid flooring material samples was investigated at a concentration of 50 to 60 $\mu\text{g}/\text{m}^3$ using ^{35}S -labeled SO_2 . The amount of SO_2 sorbed by the samples varied little with their chemical composition and was of such a magnitude as to suggest a low affinity of the surfaces for SO_2 . The sorption of SO_2 by artificial fiber carpet pile was shown to be significantly reduced by the application of dyes.

1971

1. A Climate Index for Estimating Potential for Decay in Wood Structures Above Ground. T. C. Scheffer. Forest Products Journal, v. 21, No. 10, October 1971, pp. 25-31.

Decay of wood is considerably affected by climatic conditions, hence the relative needs in different climates of protective measures for wood may vary considerably. To estimate these needs a quantitative measure of the relative potential of a climate to promote decay of above-ground wood structures exposed to the weather was developed.

2. Air Quality Criteria for Nitrogen Oxides. Environmental Protection Agency, Washington, D.C., Air Pollution Control Office, Report NAPCA-Pub-Ap-84, January 1971, 181 pp. (OM71-3)

3. Deterioration of Electrical Equipment in Adverse Environments.
M. Rychtera. Daniel Davay & Co., Inc., 946 Asylum Avenue, Hartford,
Conn., January 1971, 190 pp. (OM71-7)
4. How Materials Stand Up to Corrosion and Chemical Attack. R. J. Fabian,
J. A. Vaccari. Mater. Eng., v. 73, No. 2, 1971, pp. 36-59. (OM71-8)
5. Role of Sulfur Dioxide in Atmospheric Corrosion. D. J. Spedding. Chem.
Ind. N.Z., v. 6, 1971, pp. 39-41. (Fe71-20)
6. Sorption of Sulfur Dioxide by Indoor Surfaces--III. Leather.
D. J. Spedding, R. P. Rowlands, and J. E. Taylor. J. Appl. Chem.
Biotechnol., v. 21, No. 3, 1971, pp. 68-70.*

The sorption of SO_2 by leathers was examined at SO_2 concentrations of approximately $100 \mu\text{g}/\text{m}^3$. Sulfur dioxide was sorbed evenly over the surfaces, the sorbed sulfur being water soluble. The position on the hide from which the leather was taken had no effect on the amount of SO_2 sorbed. The uptake of gas was reduced by the application of a finish and by dyeing. The penetration of SO_2 into the samples was influenced by the organic retanning process used, condensed tannins leading primarily to surface sorption. Leather greases also reduce penetration of SO_2 . The degradation of leathers by atmospheric SO_2 was discussed.

7. The Destruction of Works of Art by Air Pollution. J. Riederer. Schonere
Heimat, v. 60, 1971, pp. 44-47 (German). (Cu71-10)
8. The Enigma of the Layered Crusts on Some Weathered Glasses -- A
Chronological Account of the Investigations. R. G. Newton.
Archaeometry, v. 13, No. 1, 1971, pp. 1-9.*

The beautiful iridescent appearance of many ancient glasses was shown by D. Brewster's studies to be due to diffraction effects arising from thin layers in a weathered crust. Of the factors that affect weathering, four stand out: (1) composition of the glass, (2) composition (particularly pH) of the moisture on the glass surface, (3) temperature, and (4) time. This paper discusses the formation of the weathered crust on glass and layer-counting as a dating technique for glass.

1970

1. Interstate Surveillance Network-1969 Data. Division of Air Quality and
Emission Data. Report NAPCA/APTD 70-3, U.S. Department of Health,
Education, and Welfare, May 1970, 203 pp. (OM70-5)

2. Sorption of Sulfur Dioxide by Indoor Surfaces--I. Wallpapers.
D. J. Spedding and R. P. Rowlands. J. Appl. Chem., v. 20, No. 5, 1970
pp. 143-146.

The sorption of SO_2 by PVC wall coverings and conventional wallpaper samples was measured at a maximum SO_2 concentration of $150 \mu\text{g}/\text{m}^3$ by use of $^{35}\text{SO}_2$. The sorption was influenced by the surface finish and design pattern of the wallpapers. Sweat deposits on the samples also influenced the pattern of uptake. The conventional wallpapers showed a greater uptake than did PVC wall coverings in all cases.

3. Sorption of Sulfur Dioxide by Indoor Surfaces--II. Wood. D. J. Spedding.
J. Appl. Chem., v. 20, No. 7, 1970, pp. 226-228.

The sorption of SO_2 by untreated wood samples has been investigated at a concentration of $90 \mu\text{g}/\text{m}^3$ by use of $^{35}\text{SO}_2$. Altered material was found in the outermost 0.05 mm of each sample and a large portion of it was water-soluble. The possible role of SO_2 in the weathering of wood is discussed.

4. Systems Analysis of the Effects of Air Pollution on Materials.
R. L. Salmon. NTIS Report PB-209192, January 15, 1970, 196 pp. (Fe70-13)
5. The Weathering and Performance of Building Materials. J. W. Simpson and P. J. Horrobin, eds., Medical and Technical Publishing Co. Ltd., 1970, 277 pp. (Fe70-17)

1969

1. Effect of Ozone and Laundering on Vat-dyed Cotton Fabric. N. Kerr, M. A. Morris, and S. H. Zeronian. Am. Dyestuff Reporter, v. 58, No. 1, January 13, 1969, pp. 34-36.**

The color of cotton fabric dyed with C. I. Vat Blue 29 decreased in depth and the hue tended toward red. Washing appeared to reduce the rate of fading. Fabric was reduced in strength by exposure to ozone. The largest strength loss was found for samples washed between exposures. The copper number and carboxyl group determinations indicated that chemical modification to cellulose was small.

2. Ozone Fading of Dyes. V. S. Salvin. Text. Chem. Color., v. 1, No. 11, 1969, pp. 245-251.

The fading of disperse dyes on cellulose acetate (I), nylon, and polyester-cotton substrates in atmospheres containing ozone was examined and related to ozone concentration, its absorption by the substrate, and the dye sensitivity. Ozone was bubbled through solutions of blue dyes;

the fading appeared to be oxidation accompanied by hydrolysis and the reaction depended on the solubility and rate of diffusion of ozone in the fabric fiber. Accelerated fading tests were conducted by using 0.05-0.2 ppm ozone concentration at 30-40 percent humidity. The fading of Disperse Blue 27 occurred at 2-5 on the international gray fading scale on cellulose acetate, cellulose triacetate before and after heat treatment, cellulose triacetate with a saponified surface, polyester dyed with and without a carrier, Orlon, and nylon 66. Fading was also examined at 85-90 percent humidity; it was more rapid, thus accounting for the fading of nylon carpets in humid climates. Ozone fading on permanent-press fabrics resulted from the reaction of the disperse dye, which had migrated from the fibers to the finish.

1968

1. Sorption of Sulfur Dioxide by Paper. C. J. Edwards, F. L. Hudson, and J. A. Hockey. J. Appl. Chem., v. 18, 1968, pp. 146-148.

Sulfur dioxide is absorbed by paper and slowly converted to sulfuric acid. The presence of this acid severely reduces the useful life of paper. The absorption of sulfur dioxide has been investigated for a representative range of papers for exposures lasting many months. The concentration of sulfur dioxide approached those found in urban atmospheres.

1967

1. Corrosion by Air Pollution. J. R. Goss. Proc. Annu. Conf., Nat. Soc. Clean Air, No. 34, 1967, pp. 75-92. (Fe67-4)
2. Cost Comparison of Protective Coatings for Steel. C. V. Brouillette, Report No. R-5015, Naval Civil Engineering Laboratory, Port Hueneme, CA, November 1967, 9 pp. (Pa67-2)
3. The Action of Environment on Museum Objects. Part I. Humidity, Temperature, Atmosphere Pollution. N. Stolow. Curator, v. 9, 1966, pp. 175-185.

The author surveys the effects of uncontrolled humidity, temperature and pollution levels on various materials in museums, and discusses a "safe" atmosphere for art objects. Psychrometers, which may be handily used to measure relative humidity throughout a museum, are available at various prices, and should be used to help establish humidity control.

1965

1. Fading of Coloring Matters. C. H. Giles. J. Appl. Chem., v. 15, No. 12, 1965, pp. 541-550. (F65-1)
2. Materials Deterioration and Air Pollution. J. B. Upham. J. Air Pollution Control Association, v. 15, No. 6, June 1965, p. 265. (Fe65-14)
3. Oxides of Nitrogen as a Factor in Color Changes of Used and Laundered Cotton Articles. V. McLendon and F. Richardson. Am. Dyestuff Reporter, v. 54, No. 9, April 26, 1965, pp. 15-21.

Oxides of nitrogen were found in drums of gas-fired household dryers in concentrations believed to be sufficiently high to produce color changes observed in certain dyed cottons as well as yellowing of used and laundered white cotton sheets and T-shirts that had been dried repeatedly in these dryers. Test procedures are described and such aspects as origin of nitrogenous compounds are discussed.

1961

1. Atmospheric Sulfur and the Durability of Paper. F. L. Hudson and W. D. Milner. J. of the Society of Archivists (London), v. 2, 1961, pp. 166-167.

This note on the tendencies of papers to pick up sulfur, using radioactive sulfur in tiny but known quantities as a tracer, states that it is possible, in exposing paper to atmospheres containing 0.5 percent sulfur dioxide by volume, to detect and measure the sulfur after 2 hours using standard counting methods for radioactive materials. The method proved more sensitive than measurement of change in acidity. A summary of results on various types of paper is given and the authors conclude that damage occurs owing to acidity included in paper when it is made, or picked up later from acid atmospheres. The rate of deterioration seemed dependent also on temperature.

1960

1. The Extent of the Paper Problem in Large Research Collections and the Comparative Costs of Available Solutions. R. E. Kingery. Summary of a Conference Sponsored by the American Library Association and the Virginia State Library (Washington, D.C.), Publication No. 16, Virginia State Library, September 16, 1960, pp. 36-41.

For many years, librarians of large research libraries have been aware that their collections were deteriorating at an alarming rate. Such deterioration is primarily due to the formation of sulfuric acid in the paper by the combined action of sulfur dioxide and humidity. Other acids from the atmosphere may also contribute to such deterioration. The

available conservation techniques are: conservation of original material and reproduction of original material. The development of a permanent durable book paper is recommended.

1959

1. Deterioration of Materials in Polluted Atmospheres. J. E. Yocum. Corrosion, v. 15, No. 10, October 1959, pp. 541t-545t. (Fe59-5)

1958

1. Durability Tests of Structural Sandwich. E. W. Kuenzi and L. W. Wood. Symposium on Some Approaches to Durability in Structures, ASTM STP 236, American Society for Testing and Materials, 1958, pp. 27-34. (Fe58-4)
2. Effect of Production Features on Building Construction of Titanium-Magnesium Plants. V. N. Romanov. Legkie Metally (Leningrad) Sbornik, No. 1, 1958, pp. 34-40 (Russian). (Fe58-5)
3. How Does Air Pollution Affect Books and Paper. W. H. Langwell. Proc. Roy. Inst. Great Brit., v. 37, Pt. II, No. 166, 1958, p. 210.

Sulfur dioxide effects on paper can cause serious damage to any type of paper (for example, brittleness of paper). Storing and treatment methods to prevent the damage are suggested.

4. Relation Between Actual and Artificial Weathering of Organic Materials. F. W. Reinhart. Symposium on Some Approaches to Durability in Structures, American Society for Testing Materials, ASTM STP 236, 1958, pp. 57-66. (P58-1)

1957

1. The Effects of Air Pollution on Buildings and Metalwork. R. J. Schaffer. Air Pollution, Edited by M. W. Thring Ed. Butterworth Scientific, London, 1957, pp. 58-71. (Fe57-5)

1956

1. A Comparison of Gas Chamber Tests of Bookbinding Leather With a Long-Time Atmospheric Exposure. C. W. Beebe, R. W. Frey, and M. V. Hannigan. J. Amer. Leather Chem. Assoc., v. 51, 1956, pp. 20-31.

Samples of bookbinding leathers, tanned in different ways, were exposed as bookbindings to atmospheric pollution for 12-19 years. Physical and chemical tests made after exposure correlated with gas-chamber tests made on the leather before exposure.

1955

1. Corrosion Aspects of Air Pollution. L. Greenburg and M. B. Jacobs. Amer. Paint J., v. 39, No. 43, 1955, pp. 64-78. (Fe55-2)
2. Service Fading of Disperse Dyes by Chemical Agents Other Than the Oxides of Nitrogen. V. S. Salvin and R. A. Walker. Textile Research J., v. 25, 1955, pp. 571-585.**

An extensive trial of acetate drapery fabrics dyed with new Gas-fast blues shows the active agents in the atmosphere as well as the oxides of nitrogen can cause fading in service. The fading is oxidative and designated as "O-fading." O-fading takes place on Dacron, acetate, and Arnel. A heat-treatment insures a marked increase in resistance to this fading. All disperse blue and some of the reds and yellows are subject to O-fading which may be inhibited by antioxidants such as diphenylethylene diamine and the nongas-fading inhibitor p-octyl phenol. Optimum resistance to atmospheric fading of Arnel is obtained by the use of inhibitor plus heat treatment. No blue disperse dye for acetate, Arnel, or Dacron is resistant to O-fading as well as to light and gas fading.

3. The Destructive Effects of Air Pollution on Materials. A. Parker. 6th Des Voeux Mem. Lecture, Proc. 22nd Annual Conf., Nat. Smoke Abatement Soc., Bournemouth, England, September 28, 1955, pp. 120-132. (Fe55-6)
4. The Permanence of Paper. IV. W. H. Langwell. Brit. Paper and Board Makers' Assoc., Proc. Tech. Sect., v. 36, 1955, pp. 199-207.

A wide range of British commercial writing and printing papers were tested for liability of damage by atmospheric SO_2 , and a suggested standard accelerated aging test was devised in which the dampened papers are exposed to 0.5 percent SO_2 for 1 week. A practical and effective inhibitor solution (1 percent $\text{Na}_2\text{H}_2\text{P}_2\text{O}_7$ and 0.1 percent $\text{K}_4\text{Fe}(\text{CN})_6$) was found applicable to the whole range of sample papers.

1954

1. Deterioration of Materials--Causes and Preventive Techniques. G. A. Greathouse and C. J. Wessel. Reinhold Publishing, New York, N.Y., 1954, 835 pp. (OM54-1)

2. Paper. C. J. Wessel. Chapt. 6 in Deterioration of Materials -- Causes and Preventive Techniques., edited by G. A. Greathouse and C. J. Wessel, Reinhold Publishing Corp., New York, N.Y., 1954, pp. 355-402.

The composition and manufacture of paper and its deterioration by chemical and biological agents as well as light, heat, and moisture is discussed.

1940

1. Atmospheric (Gas) Fading of Colored Cellulose Acetate. C. A. Seibert. Am. Dyestuff Repr., v. 29, No. 15, 1940, pp. P363-P374. (F40-1)

1939

1. Effect of Sulfur Compounds in the Air on Various Materials. L. R. Burdick and J. F. Barkley. U.S. Bureau of Mines, I.C. 7064, April 1939, 9 pp. (Fe39-1)

1937

1. The Fading of Dyeings on Cellulose Acetate Rayon. F. M. Rowe and K. A. J. Chamberlain. J. Soc. Dyers Colourists, v. 53, 1937, pp. 268-278. (F37-1)

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CHEMICAL, BIOLOGICAL AND METEOROLOGICAL VARIABLES INDEX

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- 2) Al: 75-2; 69-4; 57-1
- 3) Cu: 82-27; 81-4; 79-5; 78-12; 76-5; 71-6; 67-4; 64-3; 50-3
- 4) Ni: None
- 5) Zn: None
- 6) OM: 82-18; 74-15,16; 70-3
- 7) MSC: 78-17; 77-8; 73-4,6,15; 71-2; 57-1; 53-2; 50-1
- 8) E: 53-1
- 9) F: None
- 10) Pa: 77-9; 76-4; 54-3
- 11) P: None
- 12) ONM: None

B. Inorganic compounds

1. Halogens

a. Chlorine

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- 2) Al: 82-4; 80-13,23; 81-2; 78-4; 75-6; 74-4,5,6; 71-3,5; 70-3,5; 69-1,4,9; 68-2,6,8; 67-3; 63-2; 57-1; 56-2
- 3) Cu: 82-3,6,20,22; 81-3; 78-5,10; 71-6,7; 70-1,5; 68-1,2; 58-3; 57-3; 56-2; 50-1; 29-2

- 4) Ni: 82-2,5; 68-1
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- 7) MSC: 81-8,10,11; 80-6,13; 79-6,7,9; 78-2,27; 78-29,32,37; 77-1,10,12,14; 76-1,13,17,25,37,44; 75-12; 74-12; 75-10,13; 71-5,-8; 70-3; 66-2; 63-2; 60-1; 53-2; 50-2; 49-1,2; 37-1; 26-1; 17-1
- 8) E: 31-1
- 9) F: None
- 10) Pa: 77-9; 76-4; 75-5; 74-1,2; 71-3; 67-2; 63-3
- 11) P: None
- 12) ONM: None

b. Other halogens

- 1) Fe: 74-24; 73-9; 60-7; 58-2; 57-4; 53-1
- 2) Al: 69-1; 68-6
- 3) Cu: 82-22
- 4) Ni: None
- 5) Zn: None
- 6) OM: 78-11
- 7) MSC: 76-25,37,44; 75-12; 73-13; 60-1
- 8) E: None
- 9) F: None
- 10) Pa: None
- 11) P: None
- 12) ONM: 74-4

2. Nitrogen compounds

a. Nitrogen oxides

- 1) Fe: 82-39,40; 81-11; 80-2,18; 79-7,10; 78-12,21; 76-5; 75-11; 74-10,12; 71-12; 70-14; 68-3,18; 65-3; 64-2; 61-5

- 2) Al: 76-1; 69-4; 68-6; 53-1
- 3) Cu: 82-3; 75-3; 71-6,8; 70-10; 57-1
- 4) Ni: None
- 5) Zn: None
- 6) OM: 82-10; 79-1; 77-6; 74-15,16; 73-1; 71-3,7; 70-1,3,5
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72-9; 71-5,8; 70-3; 60-2; 53-2; 17-1
- 8) E: 79-1; 78-1; 76-1; 74-3; 67-3; 53-1; 31-1
- 9) F: 79-1,2; 76-6; 73-2; 72-1; 70-3; 69-2; 64-1; 63-1;
40-1; 37-1
- 10) Pa: 77-9; 75-1; 74-4; 71-3; 63-4; 51-1
- 11) P: 78-2; 76-7; 75-2; 74-1; 71-1,2; 70-1
- 12) ONM: 65-3; 55-2

b. Ammonia

- 1) Fe: 82-4; 80-11; 76-19; 73-6; 71-14,21; 69-3,36; 68-18;
66-2,8; 64-2; 62-4; 60-3,6; 51-1; 38-1; 35-2
- 2) Al: 76-3; 69-4; 68-6; 53-1
- 3) Cu: 71-6; 66-6; 57-1,3; 56-2; 50-3
- 4) Ni: None
- 5) Zn: 62-4
- 6) OM: 79-1; 76-8; 74-15,16
- 7) MSC: 78-15; 76-5; 75-1; 71-5; 70-3; 67-1; 63-2; 37-1;
34-1; 26-1; 17-1; 10-1
- 8) E: None
- 9) F: None
- 10) Pa: None
- 11) P: 65-1
- 12) ONM: None

c. Other

- 1) Fe: 81-16; 76-9; 68-17

- 2) Al: 69-1; 68-6
- 3) Cu: 82-22
- 4) Ni: None
- 5) Zn: None
- 6) ONM: None
- 7) MSC: 58-4
- 8) E: None
- 9) F: None
- 10) Pa: None
- 11) P: None
- 12) ONM: None

3. Ozone

- 1) Fe: 82-52; 80-2,18; 79-7,10; 78-12,21; 76-5; 75-11;
74-10; 71-12; 60-4; 55-2
- 2) Al: 76-1; 68-6
- 3) Cu: 81-3; 77-2; 62-2; 60-2; 57-1
- 4) Ni: None
- 5) Zn: None
- 6) OM: 79-1; 77-7; 74-15,16; 73-2; 71-7; 70-5
- 7) MSC: 71-2
- 8) E: 80-2; 79-1,2; 78-1; 76-1; 74-4; 69-1; 67-2,3; 66-1; 63-1;
62-1; 58-1,2; 56-1,2; 53-1,2,3; 52-1; 51-1,2,3; 50-1; 46-1;
40-1,2; 31-1
- 9) F: 79-1,-2; 76-6; 75-3; 73-2; 72-1; 70-3; 67-3; 66-i;
64-1; 63-1; 52-1
- 10) Pa: 77-9; 75-1; 74-3,4; 73-1; 65-3
- 11) P: 81-1; 78-2; 74-1,3; 70-1,2; 69-3
- 12) ONM: 78-3; 76-20; 69-1,2; 55-2

4. Carbon dioxide

- 1) Fe: 80-2; 71-12,19,21; 70-14; 68-8; 65-3,16; 58-3; 53-1;
38-1; 37-2; 35-2
- 2) Al: 53-1
- 3) Cu: None
- 4) Ni: None
- 5) Zn: 70-2;
- 6) OM: 78-11; 76-2,8,14; 70-1,3; 67-2
- 7) MSC: 80-10; 78-18,27; 77-11; 76-26,31,56; 75-5; 72-2,9;
71-5; 67-1,3; 66-2,3; 62-1; 62-2; 58-4; 57-1,2; 50-1;
34-2; 29-2; 26-1; 17-1; 08-1
- 8) E: None
- 9) F: None
- 10) Pa: 78-2; 77-9; 76-4
- 11) P: None
- 12) ONM: 73-4

3. Carbon Monoxide

- 1) Fe: 71-12
- 2) Al: None
- 3) Cu: None
- 4) Ni: None
- 5) Zn: None
- 6) OM: 70-1
- 7) MSC: 71-2; 32-3
- 8) E: None
- 9) F: 75-2; 67-3
- 10) Pa: None
- 11) P: None
- 12) ONM: 78-3

6. Heavy metals

- 1) Fe: 82-4; 69-6,7,9,11,14,15,16,19,20
- 2) Al: None
- 3) Cu: None
- 4) Ni: None
- 5) Zn: 82-19; 74-8; 72-3
- 6) OM: None
- 7) MSC: None
- 8) E: None
- 9) F: None
- 10) Pa: 75-5; 57-1
- 11) P: None
- 12) ONM: None

7. Hydrogen sulfide

- 1) Fe: 80-1; 79-7; 78-21; 71-5,21; 70-8; 69-36
- 2) Al: 69-4; 68-6; 53-1
- 3) Cu: 82-3,29; 81-3; 71-6; 76-6; 70-5; 58-3; 50-1,3
- 4) Ni: None
- 5) Zn: 70-2
- 6) OM: 82-18; 79-1; 76-8; 74-15,16; 71-4
- 7) MSC: 77-3; 73-13; 71-2; 50-1; 48-1; 46-1
- 8) E: None
- 9) F: None
- 10) Pa: 77-7
- 11) P: None
- 12) ONM: None

8. Other compounds

- 1) Fe: 69-4,5,8,17,18; 66-2; 29-1

- 2) Al: 53-1
- 3) Cu: 74-7; 50-3
- 4) Ni: None
- 5) Zn: None
- 6) OM: None
- 7) MSC: 77-8; 76-13; 56; 75-2; 72-2; 70-3,5; 49-2; 29-2
- 8) E: None
- 9) F: 55-1
- 10) Pa: 77-9; 76-4; 75-5
- 11) P: None
- 12) ONM: None

B. Particulates

1. Soiling

- 1) Fe: 80-2; 79-4; 77-4; 75-15; 74-12; 71-2,14,21; 69-26;
68-14, 19; 67-2; 66-7; 65-2; 62-6; 61-2; 58-3,7;
55-6; 51-5; 37-2
- 2) Al: None
- 3) Cu: 74-5
- 4) Ni: None
- 5) Zn: 70-2
- 6) OM: 74-15,16; 70-5; 67-2; 64-5; 58-1
- 7) MSC: 82-11; 81-3,9; 80-15; 79-6,10; 78-39; 77-1; 76-17,20; 76-
31; 75-6; 14-1
- 8) E: None
- 9) F: 75-2,3; 50-1
- 10) Pa: 63-4; 62-1; 54-2
- 11) P: None
- 12) ONM: 76-14; 74-4

2. Other

- 1) Fe: 82-4,17; 77-4; 73-21; 72-13; 71-5,21; 70-8; 68-1; 65-12; 62-6; 58-5; 35-2
- 2) Al: None
- 3) Cu: 79-5; 76-5; 73-4; 71-1,7; 70-10; 58-3; 57-3; 53-2
- 4) Ni: None
- 5) Zn: 74-8
- 6) OM: 78-10; 77-7; 76-8,18; 71-7; 70-5
- 7) MSC: 82-11; 81-3,4,9; 80-20; 79-1,6,10; 78-3,39; 77-1; 76-10,20,31; 75-2,6; 73-6,15; 71-5,6; 66-3; 63-5; 51-1
- 8) E: 67-3
- 9) F: 68-1; 67-2,3
- 10) Pa: 72-3; 63-4; 62-1; 57-1
- 11) P: None
- 12) ONM: None

II. Biological Variables

- 1) Fe: 73-23; 72-19; 55-2; 53-2
- 2) Al: None
- 3) Cu: 78-12
- 4) Ni: None
- 5) Zn: None
- 6) OM: 71-7
- 7) MSC: 82-9; 80-1; 79-3,4,6; 78-1,2,13,16,17,19,29,32,37,38; 77-17,19,21; 76-8,9,13,14,15,24,28,41,53; 75-3; 73-2; 73-4,7; 72-2; 71-5,8; 70-5; 68-4; 66-3; 64-1; 63-2; 62-2; 60-2; 57-1; 52-1; 50-1; 48-1; 46-1; 37-1; 34-2; 32-3; 29-2; 26-3; 25-1; 03-1
- 8) E: 80-2
- 9) F: None
- 10) Pa: 77-7; 76-14; 74-8; 73-2; 62-2; 54-2

- 11) P: None
- 12) ONM: 76-22; 72-1; 54-2

III. Meteorological Variables

A. Solar

- 1) Fe: 82-21,37; 80-2; 78-12; 77-11; 75; 74-18; 73-2,18;
71-21; 59-7
- 2) Al: None
- 3) Cu: 78-10
- 4) Ni: None
- 5) Zn: None
- 6) OM: 82-18; 81-3; 77-2; 75-3; 74-15; 71-7; 64-5
- 7) MSC: 82-7; 78-29,37,39; 77-5,14,17; 76-34,52; 62-2
- 8) E: 80-2; 79-1; 74-3,4; 53-1; 51-1,2; 46-1; 31-1
- 9) F: 81-1; 76-2; 75-1; 73-3; 70-2,3; 69-2; 68-1; 67-3;
66-1; 37-1
- 10) Pa: 78-1; 77-4,7; 76-7,13; 75-1,5; 74-3; 73-1; 72-4;
67-3; 54-2
- 11) P: 81-1; 80-2,3,4,6,10,11; 77-2; 76-6,7; 74-3; 73-2;
71-1,2; 70-1,3,4; 69-3; 58-1
- 12) ONM: 80-12; 76-19,22; 75-3,5; 72-1; 54-2

B. Temperature

- 1) Fe: 82-37,39,46; 81-75; 80-1,18; 79-7; 78-7,14; 77-2;
75-11; 74-11; 73-2,18; 70-4,18; 69-23,24; 68-12;
66-2,4; 65-2,16; 64-1; 62-2,5; 60-2; 59-1,3; 50-2;
48-7; 35-1
- 2) Al: 78-6; 73-1; 68-6
- 3) Cu: 60-2; 55-1; 50-1
- 4) Ni: 61-3
- 5) Zn: 80-10; 76-5; 71-4; 66-3
- 6) OM: 81-3; 78-1; 76-20; 74-15; 71-7; 66-8; 64-5; 60-4

- 7) MSC: 82-5,7,9,10,11; 81-9; 80-13,11,14,21; 78-1,8,18,35;
78-37,39,40; 77-3,5,13,14,16; 76-2,8,34,42,47,51; 76-
52,53,56; 74-5; 73-7,10; 72-2; 70-5; 67-3; 66-3;
26-1; 03-1
- 8) E: 80-2; 74-3; 69-1; 67-2; 51-1; 46-1
- 9) F: 75-1; 73-2; 67-3; 66-1; 55-1
- 10) Pa: 78-6; 77-4; 75-1; 74-3; 72-4; 67-3; 54-2
- 11) P: 81-1; 80-6,9,10; 74-1; 71-1; 70-3; 69-2; 65-1; 58-1
- 12) ONM: 80-12

C. Wind

- 1) Fe: 82-39,46; 80-18; 79-7; 78-14; 74-18; 73-2; 72-19;
69-22,23; 65-2; 60-2
- 2) Al: None
- 3) Cu: None
- 4) Ni: None
- 5) Zn: 80-7,10; 70-2
- 6) OM: 71-7; 70-5; 64-5
- 7) MSC: 82-9,7,10,11; 80-21; 78-1,37,39; 77-13; 76-8,25;
76-51,56; 75-3; 73-13; 70-5; 66-3; 62-2; 26-1
- 8) E: None
- 9) F: None
- 10) Pa: None
- 11) P: None
- 12) ONM: 80-12